ANL/EES-TM-322

Radioactive Waste Isolation in Salt: Peer Review of the Fluor Technology, Inc., Report and Position Paper Concerning Waste Emplacement Mode and Its Effect on Repository Conceptual Design

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RADIOACTIVE WASTE ISOLATION IN SALT:

PEER REVIEW OF THE FLUOR TECHNOLOGY, INC., REPORT AND POSITION PAPER CONCERNING WASTE EMPLACEMENT MODE AND ITS EFFECT ON REPOSITORY CONCEPTUAL DESIGN

by

D.F. Hambley,* J.E. Russell, R.G. Whitfield, L.D. McGinnis, W. Harrison, C.H. Jacoby, T.R. Bump, D.Z. Mraz, J.S. Busch, and L.E. Fischer

Energy and Environmental Systems Division
Engineering Geosciences Group

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NOTICE TO READERS

At the request of the Salt Repository Project Office, Argonne National Laboratory carried out a review of two Fluor Reports entitled "Draft Position Paper for Evaluation of Waste Emplacement Mode and Waste Package/Repository Impact Study." Argonne was asked to focus on Chapter 6 of the Draft Position Paper which draws comparisons between vertical and horizontal emplacement modes. The review considered completeness/appropriateness of the evaluation criteria, an assessment of the rationale used as ranking factors between the modes, and identification of any elements thought missing in the evaluation process. It was our expectation that deficiencies in the Fluor Draft Position Paper approach be identified.

The review report prepared by the Argonne panel has been used as one consideration in the further analysis of the horizontal versus vertical emplacement mode issue.

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SRPO:DKR:max:2056JD

FOREWORD

Documents are being submitted to the Salt Repository Project Office (SRPO) of the U.S. Department of Energy (DOE) by Battelle Memorial Institute's Office of Nuclear Waste Isolation (ONWI), by Fluor Technology, Inc., and by other contractors to satisfy milestones of the Salt Repository Project of the Civilian Radioactive Waste Management Program. Some of these documents are being reviewed by multidisciplinary groups of peers to ensure DOE of their adequacy and credibility. Adequacy of documents refers to their ability to meet the requirements of the U.S. Environmental Protection Agency and the U.S. Nuclear Regulatory Commission, as enunciated in 40 CFR Part 191 and 10 CFR Part 60, as well as those of the Nuclear Waste Policy Act of 1982. Credibility of documents refers to the validity of the assumptions, methods, and conclusions, as well as to the completeness of coverage.

Since late 1982, Argonne National Laboratory has been under contract to DOE to conduct multidisciplinary peer reviews of program plans and reports covering research and development activities related to siting and constructing a mined repository in salt for high-level radioactive waste. This report summarizes Argonne's review of the Fluor Technology, Inc., draft position paper entitled *Evaluation of Waste Emplacement Mode* and its final report entitled *Waste Package/Repository Impact Study.*

Argonne was requested by DOE to review the Fluor documents on October 21, 1985 (see App. A). The review procedure involved obtaining written comments on the documents from three members of Argonne's core peer review staff and from two Argonne experts and five external experts in relevant research areas. The five Argonne members of the panel met at Argonne on November 15, 1985, and reviewer comments were integrated into this report by the review session chairman, with the assistance of Argonne's core peer review staff. Panelists did not contact Fluor personnel, and none of the panelists have been involved in any programs sponsored by DOE or directed by Fluor such that their participation in the review could be construed as a conflict of interest. All of the panelists were asked whether they concur in the way in which their comments, where incorporated, are represented in this report (see App. B). The initial draft of this report was sent to SRPO on December 6, 1985. Action statements based on Fluor's response to this review report are presented in App. C.

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Documents are being submitted to the Salt Repository Project Office (SRPO) of the U.S. Department of Energy (DOE) by Battelle Memorial Institute, Office of Nuclear Waste Isolation (ONWI), by Stone & Webster [illegible], Inc., and by [illegible] contractors to satisfy milestones of the Salt Repository Project of the Civilian Radioactive Waste Management Program. Some of these documents are being reviewed by [illegible] independent groups of persons to ensure DOE of their adequacy and credibility. Adequacy of [illegible] refers to their ability to meet the requirements of the U.S. Environmental Protection Agency and the U.S. Nuclear Regulatory Commission, as promulgated in 40 CFR [illegible] and 10 CFR [illegible], as well as those of the Nuclear Waste Policy Act [illegible]. Credibility of [illegible] refers to the validity of the assumptions, methods, and conclusions, as well as the completeness [illegible].

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Argonne [illegible] by DOE to review the Fluor [illegible] on October 21, [illegible] [illegible] procedures involved [illegible] comments on the [illegible] of Argonne's [illegible] and from two [illegible] experts in relevant [illegible]. The five Argonne [illegible] at Argonne on November [illegible] comments [illegible] by the review session [illegible] assistance of [illegible] staff. Panelists [illegible] and none of [illegible] involved in any programs [illegible] directed by Fluor [illegible] in the review could [illegible] conflict of interest. [illegible] asked whether they [illegible] their comments, [illegible] in the report [illegible] draft of this [illegible] was sent [illegible] December 6, [illegible] Fluor's response to this review [illegible] presented in [illegible].

PREVIOUSLY PUBLISHED REPORTS IN THE SERIES

"RADIOACTIVE WASTE ISOLATION IN SALT"

ANL/EES-TM-242	Peer Review of the Office of Nuclear Waste Isolation's Geochemical Program Plan (Feb. 1984)
ANL/EES-TM-243	Peer Review of the Office of Nuclear Waste Isolation's Socioeconomic Program Plan (Feb. 1984) (revised July 1984)
ANL/EES-TM-246	Peer Review of the Office of Nuclear Waste Isolation's Plans for Repository Performance Assessment (May 1984)
ANL/EES-TM-254	Peer Review of the Office of Nuclear Waste Isolation's Reports on Preferred Repository Sites within the Palo Duro Basin, Texas (June 1984)
ANL/EES-TM-256	Special Advisory Report on the Status of the Office of Nuclear Waste Isolation's Plans for Repository Performance Assessment (Oct. 1983)
ANL/EES-TM-258	Peer Review of the Office of Nuclear Waste Isolation's Plan to Decommission and Reclaim Exploratory Shafts and Related Facilities (July 1984)
ANL/EES-TM-259	Peer Review of the Office of Nuclear Waste Isolation's Final Report on the Organic Geochemistry of Deep Groundwaters from the Palo Duro Basin, Texas (Aug. 1984)
ANL/EES-TM-260	Peer Review of the Texas Bureau of Economic Geology's Report on the Petrographic, Stratigraphic, and Structural Evidence for Dissolution of Upper Permian Bedded Salt, Texas Panhandle (Aug. 1984)
ANL/EES-TM-261	Peer Review of the Office of Nuclear Waste Isolation's Report on Functional Design Criteria for a Repository for High-Level Radioactive Waste (Aug. 1984)
ANL/EES-TM-262	Peer Review of the D'Appolonia Report on Schematic Designs for Penetration Seals for a Repository in the Permian Basin, Texas (Sept. 1984)
ANL/EES-TM-263	Peer Review of the Office of Nuclear Waste Isolation's Reports on Multifactor Life Testing of Waste Package Materials (Sept. 1984)
ANL/ES-147	Rationale and Methodology for Argonne-Conducted Reviews of Site Characterization Programs (July 1985)

PREVIOUSLY PUBLISHED REPORTS IN THE SERIES

"RADIOACTIVE WASTE ISOLATION IN SALT" (Cont'd)

ANL/EES-TM-290	Geochemistry of Brine in Rock Salt in Temperature Gradients and Gamma-Radiation Fields -- A Selective Annotated Bibliography (July 1985)
ANL/EES-TM-292	Peer Review of Westinghouse Electric Corporation's Report on Reference Conceptual Designs for a Repository Waste Package (Oct. 1985)
ANL/EES-TM-316	Peer Review of the Office of Nuclear Waste Isolation's Draft Report on an Issues Hierarchy and Data Needs for Site Characterization (Dec. 1986)
ANL/EES-TM-319	Peer Review of the Office of Nuclear Waste Isolation's Draft Report on a Multifactor Test Design to Investigate Uniform Corrosion of Low-Carbon Steel (Jan. 1987)
ANL/EES-TM-320	Peer Review of the Golder Associates Draft Test Plan for In Situ Testing in an Exploratory Shaft in Salt (Jan. 1987)

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Microfiche copies of the following reviewed reports are attached to the inside back cover of this report: *Waste Package/Repository Impact Study: Final Report*, Fluor Technology, Inc., Advanced Technology Division, Irvine, Calif. (Sept. 1985), and *Evaluation of Waste Emplacement Mode: Draft Position Paper*, Fluor Technology, Inc., Advanced Technology Division, Irvine, Calif. (Aug. 1985).

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SUMMARY OF RECOMMENDATIONS

The following recommendations for revising the Fluor Technology, Inc., draft position paper entitled *Evaluation of Waste Emplacement Mode* and the final report entitled *Waste Package/Repository Impact Study* have been abstracted from the body of this review report. The authors of the reviewed documents should:

1. Reevaluate the relative rankings for the various emplacement modes for the following "want" objectives. More specifically, the scoring should be revised for:

   - *Maximize safety of excavation personnel* to more adequately reflect the true relationship between the frequency of worker accidents and the amount and rate of excavation.

   - *Maximize stability of subsurface entries* to reflect that opening span, rather than opening height, is the controlling parameter. Actually, little difference exists between the identified alternatives with respect to this want.

   - *Maximize ease of excavation of emplacement entries* to reflect that the most difficult excavation is for the deep-slot emplacement options.

   - *Minimize nonuniform forces on the waste package* to reflect that stress levels with vertical boreholes are similar to those with short, horizontal boreholes.

   - *Maximize flexibility of waste package dimensions* because the scores violate basic Kepner-Tregoe scoring assumptions.

   - *Maximize preservation of waste package integrity during retrieval* because retrieval from unsleeved, vertical boreholes is not the worst option.

- *Maximize radiation protection for workers during retrieval* because the score for long, sleeved horizontal holes is too high.

- *Maximize ability to control contamination* because the scores for shallow, unsleeved holes (horizontal and vertical) are unrealistically low.

- *Maximize near-field geologic stability* because the worst case is for in-room storage rather than for vertical holes.

- *Maximize ability to handle off-normal retrieval operations* because short, unsleeved boreholes should score best and long boreholes (sleeved and unsleeved) worst.

- *Maximize simplicity of retrieval operations* because unsleeved, vertical boreholes are ranked unrealistically low.

- *Maximize industrial safety of worker* because retrieval from short, unsleeved boreholes (horizontal and vertical) is considerably easier than retrieval from slots and trenches.

2. Delete the following want objectives:

   - *Maximize ability to locate the package horizon* because sufficient flexibility exists to locate rooms in the relatively clean San Andres Unit 4 Salt.

   - *Maximize far-field geologic integrity during retrieval* because by definition the far field will be unaffected by thermal and stress perturbations caused by remining.

3. Give greater emphasis to want objectives regarding cost and use of present technology.

4. Delete the following statements from pages 1-1 and 1-2 of the draft position paper: "No thought or study was given to the impacts of this configuration [vertical emplacement] on repository construction or short[-] and long-term performance of the site" and "Subsequent salt repository designs adopted the vertical emplacement configuration as the accepted method without further evaluation."

5. Delete App. E (Worldwide Usage of KT [Kepner Tregoe] Methods) and lines 8-17 of page 1-4 of the draft position paper because they are inappropriate.

6. Adopt a formal decision-analysis procedure (such as that of the Harvard-MIT school) for the 17 identified emplacement modes.

7. Revise App. F (Hoist System Decisions and Calculations) of the impact study to more accurately reflect current technology.

8. Consider designing the underground layout to take advantage of stress-relief techniques.

9. Consider eliminating reference to fuel assemblies less than 10 years "out-of-reactor."

10. Model the temperature distribution, assuming that the repository is constructed in an infinitely large salt body. The results would help in judging the difference between a pure medium and a two-element layered medium.

11. State that the results of creep analyses must be considered tentative until they can be validated by in situ measurements.

12. Reevaluate the peak radial stresses on the waste package so that the calculated stress conditions more closely approximate expected in situ conditions.

13. Subject both documents to careful editing.

1 INTRODUCTION

How the waste packages are emplaced is one of the most important specifications for a repository in salt for permanent isolation of high-level radioactive waste. Evaluation of alternative emplacement modes and their effects on repository conceptual design is therefore one of the major tasks of the Salt Repository Project administered by the U.S. Department of Energy (DOE). This task, undertaken by Fluor Technology, Inc., is documented in two reports prepared for DOE's Salt Repository Project Office (SRPO). The first, a draft position paper, is entitled *Evaluation of Waste Emplacement Mode*; the second, a final report, is entitled *Waste Package/Repository Impact Study.*

Argonne National Laboratory conducted a peer review of the Fluor reports at the request of SRPO. Although no specific guidance was provided to Argonne by SRPO on how the review was to be conducted, a list of guidelines was prepared by SRPO to assist in the review process (see App. A). These guidelines did not limit the nature or extent of comments provided by reviewers. Written critiques of the reports were obtained from three members of Argonne's core peer review staff and from two Argonne and five external experts in pertinent disciplines. The Argonne panelists met and reviewed the submitted comments. The chairman of the peer review session then drafted the present report, with the assistance of Argonne's core peer review staff. The draft was sent to all reviewers for comment and concurrence.

The main emphasis in this review report is on the appropriateness of the identified "wants" used in the decision analysis and the relative rankings of the various emplacement modes based not only on the decision-analysis method used but also on ex post facto changes in the rankings (see Sec. 2). More technically oriented questions are addressed in Sec. 3, the decision-analysis approach is discussed in Sec. 4, and a comprehensive page-by-page commentary is provided in Sec. 5.

2 EVALUATION OF THE SEVENTEEN EMPLACEMENT MODES

2.1 ADEQUACY OF WANT CRITERIA AND VALIDITY OF SCORES

The scores for the different emplacement modes for some of the identified wants are inappropriate. In addition, some of the relative weights may not be valid. For example, want criteria related to costs are not considered critical, yet cost is used ex post facto to eliminate the emplacement alternative that scored highest. This action demonstrates that cost is more important than the weighting of the wants would indicate.

Another want that merits more weight is "maximize use of proven technology." Ignoring this want implies that Fluor and its subcontractors are insufficiently familiar with the licensing process and the role in that process of the U.S. Nuclear Regulatory Commission (NRC). Although NRC does not require that only existing technology be used in designs, it does require the use of technology that can reasonably be expected to be developed by 1998.

The 25 want criteria are discussed sequentially in the following subsections.

2.1.1 Maximize Safety of Excavation Personnel

Page 20 of App. C of the draft position paper states that "worker safety relates to tonnage of salt removed and emplacement entry height." The presumed negative effect on safety of the additional five or six feet in height required for vertical emplacement is exaggerated. It is true in a general sense that excavating a larger volume takes longer, provided the equipment used and the opening size remain constant, thereby exposing workers to the usual excavation hazards for a longer period. However, provided that adequate provision is made for ground control, safety is more a matter of worker attitude than worker exposure to hazards.

The repository project will probably include a comprehensive training program run by a skilled safety department. The volume of rock mined will therefore have little effect on the safety of workers. Indeed, if accident rates were related only to the volume mined, big mines would have the worst records. Mining industry accident statistics prove the incorrectness of this argument (Theodore Berry and Associates, 1972; Kendorski and Dunn, 1984). In summary, no real difference exists between emplacement modes as far as maximizing the safety of excavation personnel.

2.1.2 Maximize Flexibility to Locate Repository Horizon within Salt Stratum

This want is properly treated; the relative scores appear reasonable.

2.1.3 Maximize Stability of Subsurface Entries

Page 21 of App. C of the draft position paper states that "the emplacement modes requiring the least salt removal (smallest and most widely spaced entries) would have the most stable entries." This statement is false and conveys a lack of understanding of rock mechanics. In sedimentary formations such as bedded salt, opening stability is related to roof span. Room height is less important. In any case, the room dimensions for the various emplacement modes are not sufficiently different to justify different scores. Furthermore, the widths of these openings are small compared with those encountered in room-and-pillar mines. Thus, the 17 alternatives should be rated equal as regards this want.

2.1.4 Maximize Flexibility to Accommodate Localized Geologic Variations

This want is properly treated; the relative scores appear reasonable.

2.1.5 Maximize Use of Technologically Conservative Emplacement Design to Account for Geologic Uncertainties

This want is properly treated; the equal ranking of the alternatives appears reasonable.

2.1.6 Maximize Ease of Excavation of Emplacement Entries

The scores for this want need to be changed to reflect operating realities. First, the difficulties inherent in excavating the 11-ft-deep and 4-ft-wide slots are overlooked. Furthermore, new equipment would have to be developed unless manual labor were used. In any case, excavation of these slots would be slow.

Second, the statement that "single-pass excavation is easier than double-pass excavation," together with the low scores for vertical emplacement, implies that the 20-ft-high excavations for vertical holes would require double-pass excavation whereas the 15-ft-high rooms for the other options would not. The validity of this assumption depends on the method and equipment used for excavation. For example, 20-ft by 20-ft tunnels are routinely driven in a single pass using drill-and-blast techniques with two- or three-boom jumbos. If continuous miners are used, the height that can be excavated in a single pass depends on the type of machine. The rotor-type Marietta miners used in Saskatchewan potash mines can cut openings no higher than 12 ft (Mining Magazine, 1982). On the other hand, the large roadheaders manufactured by AEC, Inc., and Westfalia Lünen can cut openings 23 ft high by 30 ft wide in a single pass. Drum-type continuous miners such as the Joy 12HM9 can cut openings up to 15 ft high by 11-15 ft wide (Mining Magazine, 1982). In summary, it is wrong to assume that rooms for vertical storage would require double-pass mining while the other options would not.

2.1.7 Minimize Volume of Excavated Material

The scoring of the various emplacement modes for this want seems reasonable. However, the discussion on page 22 of App. C of the draft position paper needs to be expanded. For example, the increased excavation volume for vertical boreholes does not relate to the height of the rooms so much as to the total excavated volume of the repository. With long, horizontal boreholes, much shorter drifts are required for the same number of waste packages.

2.1.8 Minimize Nonuniform Forces on the Waste Package

The treatment of this want appears reasonable, except that the scores for vertical holes should be similar to those for short, horizontal holes. At equal distances into the walls and floor, the tangential stress levels around the opening, which become the radial stresses on the waste package, will be the same. In fact, the maximum tangential stress will occur at a depth of several feet into the walls and floor. Differences in stress level due to thin beds of impurities should not be significant when compared with the overall stress level. Thus, conditions in vertical holes will be similar to those in short, horizontal holes. The scores for this want should be reevaluated.

2.1.9 Maximize Ability to Locate the Package Horizon

This want is given a weight of 6.7 (Fig. 6-1 of the draft position paper), that is, the second highest out of 17 weightings. The implication here is that imperfections in the lower San Andres Unit 4 (LSA4) salt at the repository horizon will significantly (however defined) affect waste package emplacement. Lithology logs for the G. Friemel No. 1 corehole (Fukui, 1984, Fig. B-2) and information in Chapter 3 of the Deaf Smith County draft environmental assessment (U.S. Department of Energy, 1984a) suggest that the salt that forms the repository horizon is probably without significant imperfections over a relatively large area. Furthermore, it is doubtful that a salt stratum would ever be selected by DOE, let alone approved by NRC, if it contained imperfections significant enough to warrant case-by-case decisions as to the vertical location of waste packages. Thus, the implied premise of this want is erroneous, and the weight assigned to it is far too high.

This want (maximize ability to locate the package horizon) should not appear in any revision of the subject documents unless a convincing case can be made for its inclusion. If salt imperfections are indeed that much of a problem, sufficient flexibility exists to locate repository rooms in relatively clean salt (e.g., 2503-2518-ft interval in the G. Friemel No. 1) in LSA4 salt.

2.1.10 Maximize Radiation Protection for Workers during Emplacement

This want is properly treated; the relative scores appear reasonable.

2.1.11 Maintain Stability of Emplacement Opening

This want is properly treated; the relative scores appear reasonable.

2.1.12 Maximize Simplicity of Emplacement Operations

This want is properly treated; the relative scores appear reasonable.

2.1.13 Maximize Flexibility to Vary Package Spacing

This want is adequately treated; the relative scores appear reasonable.

2.1.14 Maximize Safety of Emplacement Personnel

This want is adequately treated; the relative scores appear reasonable.

2.1.15 Minimize Risk of Package Damage during Emplacement

This want is adequately treated; the relative scores appear reasonable.

2.1.16 Maximize Ease of Recovery from an Operational Malfunction

This want is adequately treated; the relative scores appear reasonable.

2.1.17 Maximize Flexibility of Waste Package Dimensions

The scores for this want seem to violate the basic assumptions of the Kepner-Tregoe scoring because no score of "1" (for the worst option) is awarded. The argument that there is more flexibility for in-room storage seems correct; however, the difference does not seem to be sufficient to warrant different scores.

2.1.18 Maximize Preservation of Waste Package Integrity during Retrieval

It is difficult to understand why a package in an unsleeved, vertical borehole is considered the worst case. If overcoring were employed, retrieval would probably result in less damage to the package than in some of the other options. In reality, the long, unsleeved, horizontal borehole is the worst case. The scores for this want should be reconsidered.

2.1.19 Maximize Radiation Protection for Worker during Retrieval

This want is adequately treated; most of the scores seem reasonable. However, the score for the long, unsleeved, horizontal borehole is too high. If overcoring were required for retrieval, it would be difficult to provide shielding for packages in the interior of the borehole. The score for alternative 8A should be reevaluated.

2.1.20 Maximize Ability to Control Contamination

It is difficult to understand why shallow, unsleeved holes (horizontal and vertical) were rated worst. The justification given in lines 32-36 on page 29 of App. C of the draft position paper is incorrect. These two situations could be handled by overcoring, during which exposure would be minimal. A long, unsleeved borehole is the worst case; the in-room-storage options are the next worst. The scores for this want should be reevaluated.

2.1.21 Maximize Near-Field Geologic Stability

As pointed out in Sec. 2.1.3, stability is not a function of room height. The discussion in lines 7-12 on page 30 of App. C of the draft position paper shows a lack of understanding of salt rock mechanics. The zone of influence of creep around an opening extends about three opening diameters into the rock. Thus, vertical boreholes would be in the disturbed zone; vertical boreholes would not cause an extension of the disturbed zone. The worse case is in-room storage, with the shallow slots or trenches the next worst. The relative scores for this want should be reevaluated.

2.1.22 Maximize Ability to Handle Off-Normal Retrieval Operations

Overcoring short, sleeved packages would be just about as easy as overcoring unsleeved ones. In the case of a sleeved package, a larger diameter and therefore a greater weight would have to be carried in the overcoring barrel. Long boreholes are the worst options because of their length and the difficulty in retrieving interior packages. The unsleeved, short boreholes should have the highest scores, with the short, sleeved boreholes the second highest. More weight should be given to this want objective, and the relative scores should be reconsidered.

2.1.23 Maximize Simplicity of Retrieval Operations

The logic behind the rankings for this want is difficult to understand. Sleeves would assist in retrieval; however, in a long borehole, this advantage would be offset by the difficulty in reaching packages in the interior of the hole, especially if the hole is packed with crushed salt. The simplest retrieval alternatives are short holes with sleeves, with short holes without sleeves being next. The statement that "pulling a package is more difficult in a vertical orientation" may be strictly true, but the difference in difficulty is not sufficient to justify the low ranking given to the unsleeved, vertical borehole. Furthermore, retrieval from vertical boreholes is proven; retrieval from other configurations is not. The relative scores for this want should be reevaluated.

2.1.24 Maximize Industrial Safety of Worker

The discussion in lines 1-8 on page 31 of App. C of the draft position paper is not totally correct because of the alleged difficulties with vertical orientation. Retrieval from long, sleeved boreholes can be judged safest because the number of setups would be minimized, as stated. Retrieval from short holes, whether sleeved or not, would be considerably easier and safer than that from the slots. These differences are not reflected in the scores. The relative scores for this want should be reevaluated.

2.1.25 Maximize Far-Field Geologic Integrity during Retrieval

The scoring for this want violates the basic assumption in the Kepner-Tregoe method that the worst case is given a score of "1." However, since the far field is by definition beyond the thermally influenced region of the repository, and since stress redistribution resulting from openings only extends about 500 ft or less into solid material, this want objective is irrelevant and should be deleted.

2.2 COMPLETENESS OF WANT CRITERIA

The list of want criteria is complete; however, as shown in Sec. 2.1, some of the wants are inappropriate or irrelevant.

3 ADDITIONAL TECHNICAL ISSUES

3.1 HOISTING SYSTEM DESIGN

Contrary to the statements on page 4-7 of the impact study, friction hoisting systems for payloads of 50 short tons are well within existing technology. The largest hoisting systems in North America are those installed in 1982 at the Cathedral Bluffs oil shale project. The production hoists are 170-in.-diameter, tower-mounted friction hoists designed to hoist payloads of 52.5 short tons in skips weighing 68 short tons using six hoist ropes and four tail ropes (Engineering News-Record, 1982). The total suspended loads are approximately 325 short tons, which is considerably in excess of the 252 short tons given in App. F of the impact study. Furthermore, the total suspended load as normally defined is not simply the sum of T_1 and T_2; its expression includes a term called the effective equivalent weight to account for the moment of inertia of the hoist wheel and gears. In the case of hoists manufactured by M.A.N.-GHH Sterkrade, the effective equivalent weight has a magnitude such that the total suspended load is equal to twice T_1 (M.A.N.-GHH, 1982).

Another error is the assumption that the weight of the conveyance is always 0.75 times that of the payload. This relationship, which is approximately true for skips for drum hoists, is not necessarily true for friction hoists whose conveyance weight is chosen to obtain a satisfactory T_1/T_2 ratio. Fortuitously, the assumed value (0.75) gives a satisfactory tension ratio for a counterweighted cage at the assumed hoisting depth. The weight of the counterweight is generally taken as the sum of the weight of the cage plus 0.5 times the payload.

Once the conveyance weight and payload are both known, the rope diameter can be determined using the following equation (Nordberg Mfg. Co., 1969):

$$d = \sqrt{\frac{SL + SW}{\dfrac{\dfrac{K_1}{SF} - K_2 \times L}{n}}}$$

where:

d = hoist rope diameter (in.),

SL = payload (short tons),

SW = conveyance weight (short tons),

L = hoisting depth (ft),

n = number of hoist ropes,

SF = rope safety factor,

K_1 = constant related to the breaking strength of the rope, and

K_2 = constant related to the rope weight per foot.

Values of K_1 and K_2 for commonly used hoisting ropes are given in Table 1. (Ropes with higher breaking strengths are available; however, the given factors are typical for the grades of hoist rope most commonly encountered.) Use of the above equation would eliminate the roundabout method for hoisting-system selection used by the authors.

Page 3-33 of the impact study states that the authors contacted American M.A.N. Corporation, which is the supplier for the M.A.N.-GHH Sterkrade hoists. The 1982 version of this company's *Multi-Rope Friction Winders* brochure shows eight installations with total suspended loads greater than 250 tons, and six tower-mounted hoists with wheel diameters in excess of 16.5 ft (M.A.N.-GHH, 1982). Pearse (1984) indicates that hoists can be built to accommodate up to 12 ropes. Thus, all three of the size-limit assumptions given on page F-5 of the impact study are incorrect.

In summary, the assumptions regarding the maximum conveyance and payload sizes turn out to be somewhat realistic, although they were derived from incorrect engineering assumptions. The primary reason that larger systems have not been built is presumably the lack of demand. Appendix F of the impact study should be revised to reflect current technology more accurately.

3.2 STRESS-RELIEF DESIGN FOR OPENINGS

The assumed layout, which uses pillars with large width-to-height ratios, is based on two considerations: (1) pillar stability is related to the width-to-height ratio; and (2) beyond the plastic and viscous zones surrounding openings, salt is in an undeformed state. Thus, if a pillar is large enough, the material at its core will be undeformed, and the pillar will be stable. Experience has shown that pillars in salt with width-to-height ratios greater than 4:1 are stable at mining depths up to 3500 ft (Obert and Duvall, 1967).

This type of pillar design results in a conventional layout. However, the stress levels around the emplacement rooms or waste packages could be reduced by designing a mine layout that

TABLE 1 Hoist Rope Constants

Rope Type	K_1[a]	K_2
Locked coil	61.6	0.00122
6 x 30 flattened strand	47.5	0.00090
6 x 25 flattened strand	44.7	0.00090
6 x 19 round strand	40.7	0.00084

[a]Some values were recalculated from wire-rope data in the cited source and in Lake Shore, Inc. (1980).

Source: Nordberg (1969).

incorporates stress-relief techniques. These techniques have been used with great success in potash mines in Germany and Canada for more than 15 years (Baar, 1954; 1977). In general terms, the driving of openings is sequenced to allow the rock around them to become stress-relieved. One can then drive a "protected" opening in the stress-relieved material. This opening could be either a room or a large borehole. Examples of stress-relief room layouts are given in Figs. 1 and 2. Consideration should be given to designing mine layouts that incorporate stress-relief techniques.

3.3 AGE OF WASTE AND AMOUNT OF FUEL BURNUP

Page 4-4 of the impact study states that the cladding temperature limit of 375°C could be exceeded if younger (five-year-old) spent fuel were emplaced in the repository. This evaluation is unnecessary because it has generally been assumed that waste will be at least 10 years out-of-reactor. Actually, much of the existing spent fuel is already 10 years or more out-of-reactor. By the time the first repository is ready, much of the spent fuel will be considerably older than 10 years. Furthermore, as pointed out by Dippold and Wampler (1984), there are advantages to emplacing older fuel, namely: older (i.e., cooler) waste is less costly to transport; the amount of waste per package can be

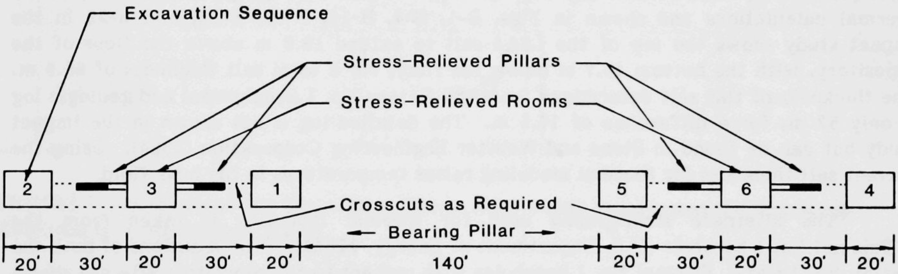

FIGURE 1 Emplacement of Waste in Horizontal Boreholes Driven in Stress-Relieved Pillars: Cross Section of Three-Room Configuration

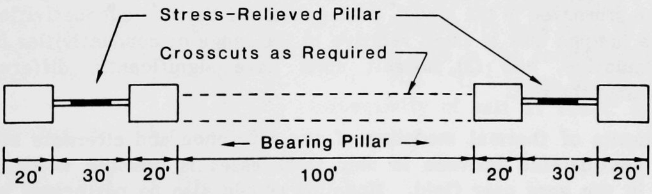

FIGURE 2 Emplacement of Waste in Horizontal Boreholes Driven in Stress-Relieved Pillars: Cross Section of Two-Room Configuration

increased; and the spacing between packages can be reduced. These advantages translate into lower costs.

Using fuel fabricated to remain in the reactor longer would require increased shielding for spent fuel waste packages. On the other hand, the volume of spent fuel needing disposal would be reduced, and the resulting lower annual throughput could be accommodated by a smaller repository. Other things being equal, higher fuel burnup would decrease costs.

Provided that spent fuel remains out-of-reactor at least 10 years before disposal, having the fuel remain in the reactor longer has some advantages. There is no advantage to disposing of 5-yr-old rather than 10-year-old fuel. Indeed, there are advantages to disposing of fuel only after it is considerably older than 10 years out-of-reactor. The authors should therefore consider not referring to fuel rods less than 10 years out-of-reactor.

3.4 STRATIGRAPHY USED IN THE DOCUMENTS

The reference stratigraphy is taken from the Detten No. 1 borehole (see Fig. 3). The only stratigraphy used in the impact study is "lumped" stratigraphy, which only distinguishes salt from nonsalt (see Fig. 4). The "lumped" stratigraphic model used in the thermal calculations and shown in Figs. B-1, B-8, B-10, B-12, B-16, and B-30 in the impact study shows the top of the LSA4 salt to extend 19.8 m above the floor of the repository, with the bottom 46.7 m below the floor, for a total salt thickness of 66.5 m. The thickness of this salt determined from the Detten No. 1 geophysical and geologic log is only 52 m, for a difference of 14.5 m. The detailed log is not shown in the impact study but can be found in Stone and Webster Engineering Corporation (1984). Using the correct salt thickness for thermal modeling raises temperatures in the near field.

The alternate stratigraphy used for thermal modeling is taken from the J. Friemel No. 1 borehole (U.S. Department of Energy, 1984a). (The locations of both the Detten No. 1 and J. Friemel No. 1 boreholes with respect to the repository site are shown in Fig. 3.) Here again, the stratigraphy used is "lumped" stratigraphy. The tops and bottoms of units indicated by the "lumped" and "raw" data are in good agreement (see Fig. 5). The thickness of the LSA4 salt is 50 m.

Such lumping is valid provided several conditions are met: (1) the thicknesses of major units are preserved in the model, (2) the range of thermal conductivities of each of the strata in a lumped unit is small relative to the range of conductivities in the model used for calculation, and (3) nonsalt units have significantly different thermal conductivities than the salt.

The results of thermal modeling of the reference and alternate stratigraphies suggest that considerable latitude in unit thicknesses is possible without modifying temperatures in the very near field. Modeling should also be performed in which the respository is assumed to be constructed in a salt of infinite dimensions. The results would help to determine the difference in temperature distribution between a pure medium and a two-element, layered medium.

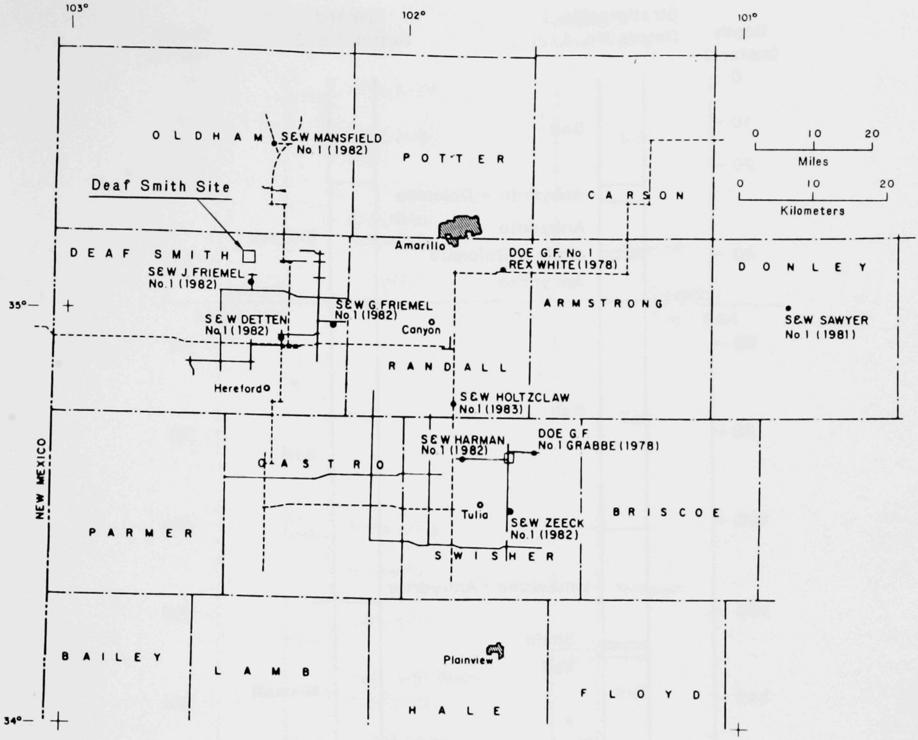

FIGURE 3 Locations of the Repository Site in Deaf Smith County and the Boreholes Referred to in the Impact Study

3.5 THERMAL PROPERTIES USED IN ANALYSES

Table B-1 in the impact study accurately relates thermal properties obtained from DOE reports. However, serious discrepancies occur in the text. For example, Table B-1 gives equations used in DOE reports for thermal conductivity. The impact study states that an average value for thermal conductivity was used in the thermal modeling. It further states that the average value used is the conductivity of salt at 110°C. However, the value actually used is 4.7 $Wm^{-1}{}^{\circ}C^{-1}$ (page B-17), which is 7% higher than 4.38 $Wm^{-1}{}^{\circ}C^{-1}$, the thermal conductivity of salt at 110°C as calculated using Eq. 1 (Lagedrost and Capps, 1983):

$$K(T) = 6.02 - 1.84 \times 10^{-2}T + 3.2 \times 10^{-5}T^2 \tag{1}$$

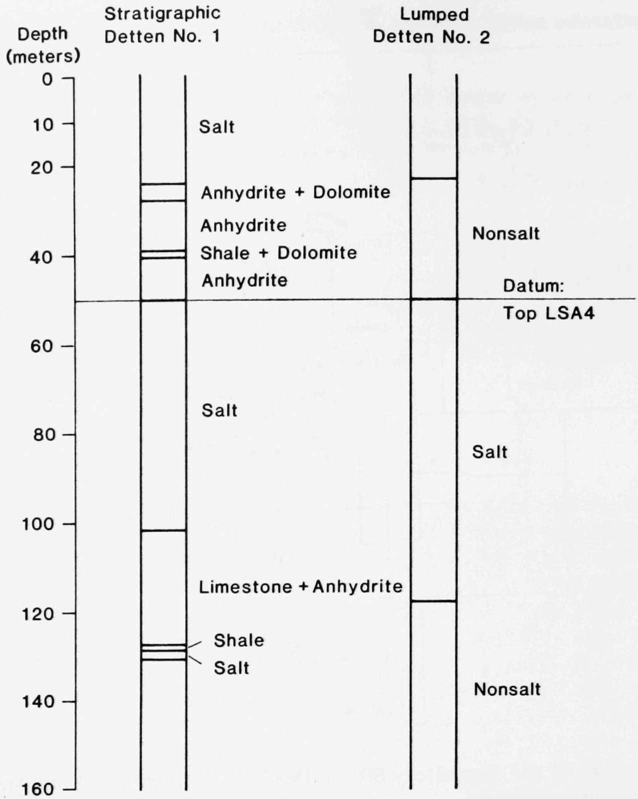

FIGURE 4 Comparison of the "Lumped" and "Nonlumped" Stratigraphy of the Detten No. 1 Borehole Used in Thermal Modeling

Data for the thermal conductivity of salt are also given in the draft environmental assessment for the Deaf Smith County site (U.S. Department of Energy, 1984a, Table 3-11, page 3-82). Those data are for salt outside the county, but still within the Palo Duro Basin. The average value given for salt from several formations is 3.15 $Wm^{-1}{}^{\circ}C^{-1}$. If this value also applies to salt at the Deaf Smith County site, the value used by Fluor for thermal modeling is 34% too high. The value given in Table 3-11 cited above for the lower LSA4 salt is 3.54 $Wm^{-1}{}^{\circ}C^{-1}$. This latter value is 33% less than the value used in the impact study. If either of these latter values for thermal conductivity had been used, the effect would have been to raise the temperature of the salt near the waste package.

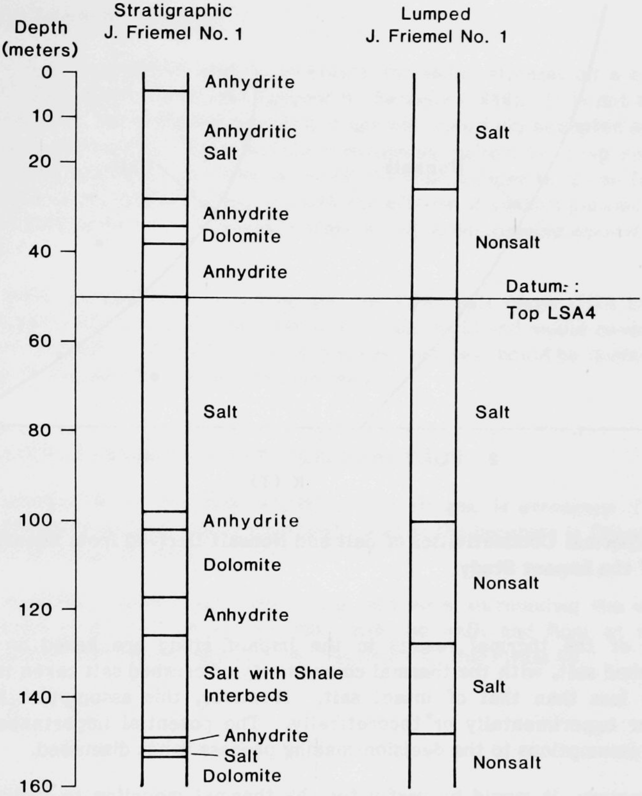

FIGURE 5 Comparison of the Alternate "Lumped" and "Non-lumped" Stratigraphy in the J. Friemel No. 1 Borehole

Curves for $K_{(salt)}$ and $K_{(nonsalt)}$ as a function of temperature, as derived from the equations in Table B-1, are shown in Fig. 6. The value used in the impact study for $K(T)_{nonsalt}$ is not given. Therefore, the value of $K_{nonsalt}$ at 110°C used in modeling was calculated using Eq. 2.

$$K(T) = 3.22 - 9.33 \times 10^{-3}T + 1.16 \times 10^{-5}T^2 \quad (2)$$

$$K(110°C) = 3.22 - 1.0263 + 0.14036$$

$$= 2.33$$

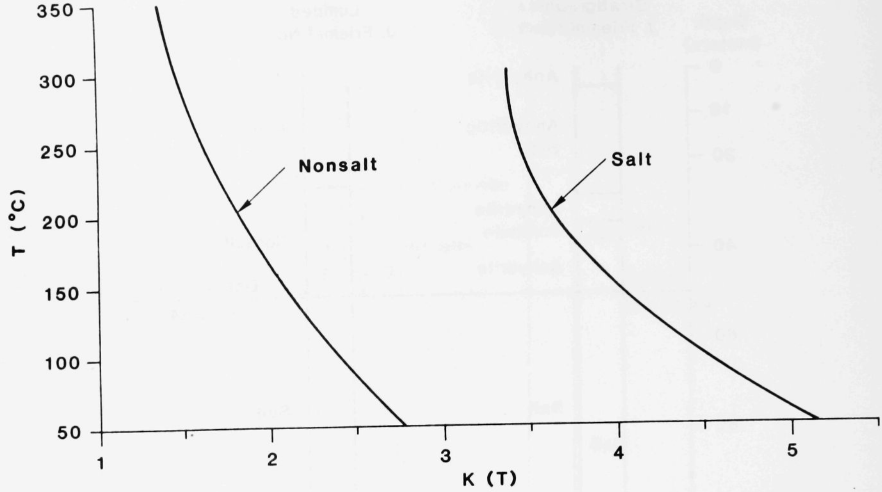

FIGURE 6 Thermal Conductivities of Salt and Nonsalt Derived from Equations in Table B-1 of the Impact Study

Many of the thermal results in the impact study are based on calculations involving crushed salt, with the thermal conductivity of crushed salt taken to be an order of magnitude less than that of intact salt. However, this assumption has not been verified either experimentally or theoretically. The potential importance of this and several other assumptions to the decision-making process is not discussed.

In summary, it would be useful for the thermal modeling to include a "worst-case" thermal conductivity. Also, lithologies adjacent to the salt include anhydrite, dolomite, and some thin shales. The nonsalt units in the "lumped" stratigraphic model do not all contain similar proportions of these other rock types. Furthermore, the properties assumed for nonsalt were taken from Lagedrost and Capps (1983) for the Davis Canyon site above Cycle 6 (RE/SPEC, 1984). However, inspection of the stratigraphic column for Davis Canyon (U.S. Department of Energy, 1984b) indicates that the nonsalt rocks are primarily limestone, sandstone, and shale, rather than anhydrite and dolomite. The tables for the thermal conductivities of rocks in Clark (1966) indicate that the conductivities of anhydrite and dolomite are similar to that of salt, whereas those of limestone, shale, and polyhalite are considerably less. This analysis suggests that the "lumped" values used are conservative for the Deaf Smith County site but are not necessarily realistic. These limitations in methodology are not discussed in the impact study.

3.6 CREEP BEHAVIOR OF SALT

The creep formulation used to calculate the radial stresses on a waste package (page C-15 of the impact study) was derived by Senseny (1983). It is not a constitutive law but an empirical curve-fitting relation; it has not been fully accepted as valid by the rock mechanics community. Considerable controversy surrounds creep relationships in salt rock, and long arguments could ensue about the relative merits of one formulation or another. Handin et al. (1984) studied in depth the effects of various parameters on creep and concluded that more work is needed before an all-encompassing constitutive law can be developed.

The yield strength of ∞ (infinity) for the LSA4 salt (page C-14 of the impact study) is incorrect, for it implies that salt is infinitely rigid and would never yield -- the exact opposite of reality. The results of any creep analyses should be declared tentative until they can be validated by in situ measurements.

3.7 PEAK RADIAL STRESSES ON THE WASTE PACKAGE

The assumption in the impact study of an air gap is erroneous if the annulus around the package is packed with crushed salt. Unless the borehole is fitted with a rigid sleeve, creep will result in closure.

The maximum tangential stress in the salt rock surrounding the emplacement rooms will occur at a depth of several feet into the walls and floor at the boundary between the plastic and viscous zones. The magnitude of this stress is:

$$\sigma_t = \sigma_o + \kappa \tag{3}$$

where:

σ_t = tangential stress,

σ_o = primitive stress, and

κ = shear stress.

By definition, the value of κ at steady state conditions at the plastic/viscous interface is k, the Prandtl yield limit, which has been found to be approximately 9 MPa for several different salt rocks. There will also be a thermal stress, due to the thermal gradient, that would be added to the stress identified above. Therefore, given that σ_o = 17.6 MPa, the maximum tangential stress is:

$$\sigma_t \geq 17.6 \text{ MPa} + 9 \text{ MPa}$$

$$\geq 26.6 \text{ MPa}$$

This stress is the radial stress to which the package would be subjected. Therefore, contrary to the analysis presented in the impact study, the peak radial stress would not be less than 21.4 MPa, using the present layout. These radial stress analyses should be reevaluated.

3.8 CONSIDERATION OF HORIZONTAL PLACEMENT IN PREVIOUS STUDIES

The statement on page 1-1 of the draft position paper that "no thought or study was given to the impacts of this [vertical emplacement] configuration on repository construction or short[-] and long-term performance of the site" is not correct, nor is the statement that "subsequent. . .designs adopted the vertical emplacement configuration. . .without further evaluation" (pages 1-1 and 1-2). Section 5.2 of Kaiser Engineers (1978) makes it clear that thermal analyses were carried out for horizontal placement.

Vertical emplacement was selected because it placed the heat sources as far from the primary structural members (pillars) as possible, thus leading to lower pillar temperatures (i.e., less pillar creep) and greater room stability. Further, vertical emplacement and retrieval had been demonstrated in Project Salt Vault, at least for a relatively short period of time. During the late 1970s, the retrieval period was generally taken to be about five years, and the rooms were to remain open during the retrieval period. Consequently, minimizing pillar creep was important. Emplacing waste in the pillars made little sense for that retrieval situation.

Nevertheless, many other options, including both short, horizontal holes and long, horizontal holes between rooms, were considered along with very deep holes that would contain multiple waste packages. The advantages of horizontal emplacement were that less salt had to be mined and room heights could be lower, both of which reduced costs during repository development. Further, environmental problems associated with disposing of the leftover salt on the surface were minimized. This point seems to have been missed in the reviewed documents.

In summary, horizontal holes were considered in earlier studies. Vertical emplacement was selected based on engineering judgment, with the pros and cons of various alternatives having been considered. Statements to the effect that earlier studies did not consider horizontal emplacement are incorrect and should be deleted from the draft position paper.

4 RANKING THE EMPLACEMENT MODE ALTERNATIVES

Review of the overall method used to rank the 17 alternative emplacement modes resulted in a need for limited examination of the Kepner-Tregoe methodology as it was applied in evaluating the list of musts and wants. Such examination falls within the scope of the DOE guidance letter (see App. A), wherein panelists were asked to consider the "evaluation rationale."

As shown in Table 2, the last three steps in the ranking process were Kepner-Tregoe weighting and scoring, adverse consequence analysis, and final emplacement mode selection. Engineering judgment was involved in all three of these steps and economic considerations were considered only in the final step. The table illustrates that the Kepner-Tregoe methodology figured prominently in the "balanced-choice" selection of the most favorable emplacement option (see page 5-9 of the draft position paper).

The authors' attempt to systematically tackle a very complicated problem with far-reaching implications is commendable. They recognized the need to use a formal decision-making methodology that explicitly states assumptions, data, and judgments so that others can review and reproduce the results. To an extent, the authors succeeded in their efforts. The draft position paper is fairly complete and understandable. In fact, its thoroughness and organization facilitate independent review. However, critical weaknesses in the analysis render it subject to criticism.

TABLE 2 Steps, Bases, and Results of the Fluor Evaluation of Alternative Waste Emplacement Modes

Step	Basis	Result
Conduct initial screening process	Subjective judgments	Reduction of 60 possible emplacement modes to 17 alternatives
Formulate broad evaluation guidelines	Assumptions	Bounds for evaluation process
Develop evaluation criteria	Engineering judgments	Lists of musts and wants
Kepner-Tregoe weighting and scoring	Engineering judgments	Impartial evaluation of musts and wants
Adverse consequence analysis	Engineering judgments	Narrowing of alternative emplacement modes
Final emplacement mode selection	Economic considerations and engineering judgments	"Balanced-choice" final selection

The need to use a formal method like decision analysis to evaluate waste emplacement modes is strongly supported by the following characteristics of the problem:

1. *Many alternatives.* Seventeen emplacement modes, selected from a much larger initial list, were evaluated in detail.

2. *Multiple conflicting objectives.* Twenty-five want objectives were considered in the final analysis.

3. *Uncertainty.* The actual characteristics of the alternative emplacement modes were not completely known and could not be predicted at the time the analysis was conducted.

4. *No overall experts.* Technical judgments had to be obtained from diverse recognized experts.

The balanced-choice approach addresses the first issue comprehensively, treats the second inadequately, neglects the third almost entirely, and handles the last somewhat arbitrarily. With respect to item 4, for example, the authors make a critical value judgment about the cost effectiveness of sleeving that seems arbitrary and indefensible.

The balanced-choice methodology inadequately conforms to several important aspects of formal decision analysis, as discussed in Secs. 4.1-4.5. Indeed, the Fluor methodology, however well organized and documented, is little more than a collection of expert judgments. Fluor should undertake formal decision analysis of the Harvard-MIT school of thought (Keeney and Raiffa, 1976; Keeney, 1980; Keeney, 1982) when revising the draft position paper.

4.1 MULTIPLE CONFLICTING OBJECTIVES

At least three weaknesses are apparent in the manner in which the authors address the issue of multiple conflicting objectives: (1) the nature of the rating scales used, (2) the meaning of the scales used, and (3) the meaning of the weights used to attach importance to the various want objectives.

The authors used what are commonly known in the field of decision analysis as "constructed scales" to measure the degree to which the various objectives are met by each of the alternatives. Peer reviewers were concerned that no "natural scales" were used. For example, in the excavation category, the last want deals with the volume of excavated material. A constructed scale was used: a score of 10 is "best" and a score of 1 is "worst." It would have been both natural and straightforward to simply use the actual volume to be excavated instead of a largely undefined, constructed scale. Natural scales, if they are appropriate, have many advantages over constructed scales. They are usually easier to understand and infinitely divisible, and intermediate levels have unmistakable meaning. In addition, utility functions can be (and usually are) used to capture the relative value of different levels of achievement for each objective. Utility functions, if properly derived, can even be used to capture risk preferences (i.e., preferences or values under conditions of uncertainty).

When constructed scales are used, it is crucial that the various points on the scales be clearly defined. Except for the vague labels "best" and "worst" for the maximum and minimum values on each of the constructed scales, all of the points are undefined. Typically, this type of scale requires precisely worded definitions of the meaning of a "1," a "2," a "3," and so on. Without such definitions, the scale is essentially meaningless. The scales used by the authors incorporate some very strong assumptions about the relative value of points on the scale. Implicit is these assumptions is that a change in a score for a particular want from a "1" to a "3" is as desirable as a change from an "8" to a "10." If the scale has this characteristic, then the scale is fine. However, no evidence was found in the Fluor documents that this is the case or that this requirement was ever considered. It is conceivable that a few of the scales have this characteristic, but doubtful that all 25 of them do.

The final weights used to compute an overall weighted score for each alternative emplacement mode were derived through a process of group consensus that is poorly described. Fundamental to the process is determination of "paired-comparison tally points." Is this a simple "voting" method? How are differences in opinion among experts reflected in the process? Indeed, how is a weight calculated when complete consensus is not achieved? Voting methods, as discussed at length in the decision-analysis literature, are filled with pitfalls and weaknesses that must be guarded against. The Fluor documents do not indicate that appropriate safeguards were taken.

For weights to be useful, the relative importance of levels of achievement of the various objectives should be considered. In decision analysis, such consideration is essentially accomplished by determining scores for pairs of objectives that are equally desirable. To use the Kepner-Tregoe analysis as an example, if the scales had meaning and a "7" on the excavated material objective were as desirable as a "5" on the ease of excavation objective, then a relative weight for the two objectives could be determined. Twenty-five pairs of comparisons are needed to uniquely determine the weights for the problem considered here, provided that two very strong independence conditions (known in the field of decision analysis as "utility independence" and "preferential independence") hold. If these independence conditions do not hold, then one more relationship must be determined. Experience indicates that such independence conditions generally do not hold. Thus, it is critical to check these conditions. There is no evidence in the reviewed documents that these conditions were verified or even considered. However, the form of the overall weighted score algorithm used assumes that these conditions hold.

Because the scores (and possibly the weights) are not properly specified, it is wrong to attach any significance to the overall weighted scores that are computed. Therefore, it is impossible to interpret the meaning of different scores. The document strongly implies that horizontal emplacement modes are far better than vertical emplacement modes because the horizontal mode chosen has a score of 69.1, while the main contending vertical mode has a score of only 53.3. In fact, it is impossible to tell how much better the horizontal method is (if it is at all, in view of the questions surrounding the way in which the weights and scores were determined). If the weights and scores had been determined in a theoretically sound manner, then such questions could be addressed.

4.2 UNCERTAINTY

The authors neglected the issue of uncertainty almost entirely, even though the actual characteristics of alternative emplacement modes some time in the future cannot be completely known or predicted at this time. It is apparent from the draft position paper that the judgments of the experts consulted were at times different. This situation can itself be interpreted as an indication of uncertainty. If these differences of opinion had been incorporated into the analysis in a formal, or quantitative, manner, then the analysis would be much more comprehensive and sound, both from a theoretical and a practical point of view.

The authors address the issue of uncertainty to a degree through consideration of "potential adverse consequences," which is a form of risk assessment. However, the process is entirely qualitative. It would have been relatively straightforward for the authors to have quantitatively included uncertainty in their analysis by at least using the diverse judgments of the expert panelists. This action would have greatly enhanced the depth of the analysis. For example, in the scoring for a particular want, single-valued scores were always listed in the tables. Single values imply exact knowledge about the performance of all alternatives on all of the objectives. Uncertainty could have been incorporated explicitly into the analysis at this point by assigning the probabilities of actually obtaining a "1," a "2,". . . , or a "10." The differing judgments of the experts could have been used to set these probabilities. For those cases that are known with certainty, a probability of 1.0 can be assigned to the proper score. Use of probability in the manner suggested affords an element of flexibility and generality that no single-score approach can ever hope to attain.

4.3 EXPERT ENGINEERING JUDGMENTS

A group of "experts" determined the weights and individual scores. Since individual judgments are not documented, it is impossible to assess the degree to which an individual expert agreed or disagreed on any of the issues. Also, it is not known whether the individuals involved were considered to be "expert" on all issues. For example, it is apparent that few if any of the "experts" had salt mine operating experience. Further, the draft position paper should have clarified whether every "expert" expressed judgments on every item.

Weights and scores are listed that were determined through a process of "group consensus," presumably an important part of engineering judgment in the balanced-choice method. It is important to know how group consensus was achieved before the validity of these results can be properly assessed. For example, were Delphi methods used? Delphi methods have been soundly criticized in the literature, even by staff members at the Rand Corporation (Sackman, 1974) where the methods originated. One danger of consensus-forcing methods is that an important source of information is lost -- the uncertainty inherent in the differing opinions. Also, it is very often the case that a "leading authority" dictates the "consensus." When this happens, the final value is not a "group consensus," but rather a "consensus of one." The U.S. Environmental Protection Agency has recognized this difficulty, and its Office of Air Quality Planning and Standards goes to great lengths (Feagans and Biller, 1981; U.S. Environmental Protection Agency, 1983) to prevent experts from influencing one another in the risk assessments that it conducts.

4.4 ECONOMIC CONSIDERATIONS

Cost was not an objective in the Kepner-Tregoe analysis. However, the cost of sleeving was considered as part of the balanced-choice reasoning process. The cost was estimated to be $400-900 million (in 1985 dollars). Because no estimates of total system cost are provided, it is impossible to put this cost in perspective. Nonetheless, the statement is made that because ". . .the cost of sleeves is high and the need for retrieval is considered of low probability. . .it is not recommended to burden the repository program economics with the additional expense of the sleeve." This statement constitutes a value judgment regarding the desirability of meeting the 25 objectives listed *and* cost.

The highest scoring horizontal-emplacement mode (a *sleeved* hole) has a score of 75.6. The recommended emplacement method (an *unsleeved* hole) has a score of 69.1. The obvious implication is that it is not worth $400-900 million to obtain an increase in score of 6.5. This value judgment is reached without any sense of what it means to have a score of 69.1 versus 75.6. As discussed in Sec. 4.3, the meaning of any of these scores is difficult to interpret. If this difference in score is not meaningfully large, then the recommendation to reverse the order is more or less supportable. However, this reversal brings into question the strength of preferences for horizontal emplacement versus vertical emplacement.

4.5 IMPLIED REQUEST FOR READER ACCEPTANCE OF FLUOR'S USE OF THE KEPNER-TREGOE DECISION METHODOLOGY

Appendix E of the draft position paper is entitled "Worldwide Usage of Kepner-Tregoe Methods." The appendix consists of hundreds of names of "public and private organizations from around the world [that] are currently using Kepner-Tregoe management ideas." While "use of Kepner-Tregoe methods" may or may not be equivalent to "use of Kepner-Tregoe management ideas," it is clear that inclusion of App. E implies a request for the reader's acceptance of Fluor's use of the Kepner-Tregoe decision-analysis methodology. Inclusion of the appendix seems to be a thinly veiled attempt to obtain reader acceptance of the Kepner-Tregoe methodology through the principle of social proof. This principle states that one important means that people use to decide what to believe or how to act in a situation is to look at what other people are believing or doing. "The principle of social proof can be used to stimulate a person's compliance with a request by informing the person that many other individuals (the more, the better) are or have been complying with it" (Cialdini, 1985, p. 137). However, the use of Kepner-Tregoe decision methodology by Fluor and others should not form the sole basis for acceptance of the methodology. Appendix E should be deleted from the draft position paper. The Kepner-Tregoe methodology should be judged on its own merits.

5 PAGE-BY-PAGE COMMENTARY

5.1 COMMENTARY ON *WASTE PACKAGE/REPOSITORY IMPACT STUDY*

Page(s)	Line(s)	Comment
iv	17-18	The equivalent number of boiling-water-reactor assemblies should be given.
x	3-4	Transporting a 42-t package (16 ft long, 48-in. diameter) should present no problem.
x	7-10	This sentence should be revised to read: ". . .the preferred transportation vehicle, which was determined to have crawler traction with skid steering,. . . . Also, during emplacement, 20-ft rooms will be "tight" for a clearance width of 18 ft -- during emergency recovery of waste packages, impossible.
x	18-19	The assumed maximum payload of 52 t is similar to that for the production hoists for the Cathedral Bluffs oil-shale mine in Colorado. However, it is the maximum that has been designed, not the maximum that can be designed.
x	29	"Could" should be changed to "will."
xi	5	Changes in the mine design or layout in response to changes in the "heat content" of packages will create monumental problems leading to errors and failures. Waste packages, from an operational standpoint, must be of approximately the same "heat content." The horizontal configuration of emplacement holes may occasionally be adjusted, but even this type of accommodation is undesirable.
2-1		Section 2 does not completely prepare the reader for the subsequent report sections. In particular, Sec. 2 should summarize the important data used in the analyses (e.g., physical properties and loads). Table 2-2 (page 2-5), which gives the main parameters of the reference waste package design for consolidated spent fuel, should be relegated to an appendix.
2-3		Retrievability for 50 years after initial emplacement (parameter DB10) is an NRC requirement (10 CFR 60.111[b]), not a DOE assumption.

Page(s)	Line(s)	Comment
2-5		Drilling a 90-cm vertical borehole poses no problem. However, if a horizontal borehole is to be drilled, the length of the hole will be important. A long, horizontal borehole will deviate substantially from the horizontal plane. In addition, unless the horizontal borehole is "cased," difficulty will be experienced in centralizing the waste package. Failure to centralize the waste package will place it in contact with the bottom of the borehole. This configuration will result in preferential heating of the bottom of the borehole and a tendency for the waste package to migrate downward. Such movement will cause major problems if retrieval proves necessary. If a package 446 cm long is buried in a hole 587 cm long, it will be in the zone of maximum stress. In other words, whether emplaced in a vertical or horizontal borehole, the package will be subjected to the maximum possible dilation and movement. In the case of vertical emplacement, an inordinate amount of floor "heave" may occur. The depth of cover should be reevaluated.
2-6		Waste emplacement would be most efficient in a retreat mode, using pillars on both sides of the main entries.
3-1		Although DHLW (defense high-level waste) and WVHLW (West Valley high-level waste) are mentioned in Table 2-1 (page 2-2), and BWR (boiling-water-reactor) wastes are included in Table 2-2, Sec. 3 does not say whether these waste forms were considered and why PWR (pressurized-water-reactor) waste in a 12-assembly package was chosen as the "reference" waste package.
3-6	12-14	Heat loads are not given in Table 3-3 as stated.
3-6	22-23	These lines are not a complete sentence. They probably constitute a subordinate clause to the previous sentence.
3-7		Footnotes (e) of Tables 3-1 and 3-2 state that the initial power is based on 33,000 MWD/MTU. Table 3-3 should also give the initial power and provide the power levels over time for the three cases.
3-8	1-20	Some temperature measurements were made at the time the initial fuel-rod-consolidation tests were carried out at Oak Ridge National Laboratory. Different models can be

Page(s)	Line(s)	Comment
		used to calculate the temperature difference, which may result in differences large enough to raise doubts about how many PWR assemblies produce the limiting temperature difference. Therefore, sufficient experimental consolidation tests must be conducted to resolve the question. Proper consolidation may result in extensive rod contacts and conductive heat transfer.
3-8	5	Cladding temperatures of 375°C can result in stress rupture of the cladding within 100 years. This finding means that the discussion regarding the undesirability of cladding breach (page 3-38, lines 21-29) should be reconsidered.
3-8	14-17	These lines are not a complete sentence. They appear to be a subordinate clause to the previous sentence.
3-9	20-26	Item 9 does not consider the possibility that crooked rods may come into contact with each other.
3-13	17	The variability in the thermal conductivity of salt should be accounted for. Using an average value over a temperature range does not result in a conservative analysis.
3-14		Emplacement within a pillar or in a floor borehole should prove superior to emplacement on the floor, in a floor slot, or in a trench excavated in the floor. A waste package not confined in a borehole will be subject to greater displacement than one confined to a borehole. Such movement will make retrievability very difficult. In the extreme case, a waste package emplaced in a slot in the center of the floor might be found at the time of retrieval in a position at or near the original roof. Also, if rooms are backfilled with salt, and a borer or continuous miner were used to reopen rooms, in-room emplacement, and possibly slot emplacement in the floor, would present a hazard. In an undisturbed state (with respect to thermal loading), mine pillars are more stable at their centers. Emplacement too near an excavated surface may make retrievability difficult.
3-15	13-16; 21-23	The temperature at the center of a backfilled room will be higher for horizontal emplacement if there are storage holes in both pillars.

Page(s)	Line(s)	Comment
3-16	11-16	To maintain roof-to-floor closure within acceptable limits for five years, the maximum allowable areal thermal loading for spent fuel at the Deaf Smith County site is about 8.5 W/m^2 (RE/SPEC, 1984). The subject study mentions a maximum allowable areal thermal loading of 24 W/m^2. From the standpoint of economics, it would be desirable to keep areal loading as high as practical.
3-16	21-23	The variation in the thickness of the crushed salt in the annulus is mentioned. However, the size or size distribution of this crushed salt is not mentioned. The smaller the gap, the more difficult it will be to fill it with crushed salt. Both the salt particle size and the annulus loading procedure will be problem areas. Conformity to specifications will be difficult to achieve and monitor. In a horizontal hole, maintaining a gap or loading such an annulus would be impossible from a practical standpoint. Under normal circumstances, holes drilled in salt can have near-perfect walls and can meet the specified hole diameter within a fraction of an inch. The waste package can be centered within the borehole with ceramic centralizers.
3-16	27-29	Figure 3-3 indicates that only about "one" inch of crushed salt could be tolerated. The two-inch air gap applies to the PWR-9 package, not the PWR-12.
3-16	29-32	Figure 3-3 does not give values for an areal thermal loading of 24 W/m^2. By interpolating between the curves for 20 W/m^2 and 30 W/m^2, one can infer such values. Furthermore, the stated air gap is for a PWR-9 package, not the PWR-12.
3-17		Figure 3-2 should give the ambient temperature at the burial horizon or a temperature-increase scale.
3-19	28-30	This sentence seems to indicate that horizontal borehole emplacement was prejudged to be superior. Anticipating conclusions drawn later in the report is not good report presentation. The words "preferred" and "(Section 3.4)" should be deleted.
3-20	10-17	The stress levels given here do not agree with underground observations.

Page(s)	Line(s)	Comment
3-20	18-21	This paragraph overstates the situation. For the cases considered, very simple analyses have been used, and the results have not been validated in the field. Such a positive statement is not justified.
3-20	22-27	Field validation is needed to support the statement "that an air gap will eliminate the threat from a concentrated load on one side of a package." The analyses neglect the salt buildup observed in the relatively short time of the Avery Island full-scale heater tests.
3-20	24-27	Drift or pillar walls will tend to slab, thereby creating vertical shear planes perpendicular to the centerline of the horizontal borehole. These vertical shear planes will occur en-echelon, with the vertical displacement diminishing away from the salt face. With 60-70-ft-square pillars having a height of 20-30 ft, this effect is visible to a depth of 3-4 ft. This shearing is independent of the pillar dilation that occurs in the midsection of the pillar. If a horizontally or vertically emplaced waste package is located near the floor or rib surface, it may experience a "grabbing" or shearing action during rib slabbing or floor heaving.
3-20	28-29	The analysis presented in App. C is for a horizontal slot, not for a horizontal borehole.
3-20	30	Centralizers, rather than crushed salt, should be relied on to maintain the required air gap.
3-20; 3-21	30-31; 1-2	The influence of the air gap is exaggerated. The air gap will not reduce the radial stress on the waste package as claimed here.
3-21	6-9	For trench emplacement, a safe minimum depth may prove to be approximately half the room width.
3-21	22-23	Buckling is highly unlikely, given the thickness of the package.
3-23	7	The feasibility of emplacement equipment should not be discussed without considering the work done by Robbins Co. (1985) and others regarding horizontal storage. Also, units should not be mixed. Both metric and English units are being used.

Page(s)	Line(s)	Comment
3-23	11-13	A predetermined height controlled to plus or minus six inches may interfere with selecting the most appropriate geological horizon with respect to local anomalies. However, it is doubtful that the repository horizon will have anomalies of such a magnitude that accommodation will be necessary.
3-23	18-20	The rooms should be bigger.
3-23	23-26	These lines imply that the transport vehicle and emplacement machine will be different. Transfer of the transfer cask and waste package from the transporter to the emplacement machine may be hazardous. The same machine should be used for transport and emplacement. Machine weight will not be a problem.
3-24		The scissors support shown would not be stable unless the arms were pinned together at the middle. Even if pinned, the arms appear quite "light" and would not allow any package overhang. The indicated support of the package and transfer cask by the counterbore wall is necessary, and antifriction devices must be provided.
3-26	1-5	The crawler-type machines will operate satisfactorily for the intended use. However, in modern salt mines, rubber-tired vehicles are used for hauling, undercutting, and loading. The primary reasons for the change are increased mobility and speed and reduced maintenance. As to weight, 50-short-ton and 100-short-ton trucks are common pieces of haulage equipment in salt mines. Rubber-tired equipment with leveling jacks is recommended. In addition, the tire size must be smaller than the smallest hoisting shaft compartment.
3-26	15-19	Currently used mining equipment can be modified to function as emplacement-transport vehicles. Hydraulic drills used at salt-mining faces have some of the required alignment features. This equipment does not pose problems.
3-26	19-21	This sentence should be revised to read: "It will need to be capable of supporting the large cantilevered load that develops as the transfer cask is directed toward the pillar."

Page(s)	Line(s)	Comment
3-27	11-15	It cannot be automatically assumed that establishing the feasibility of emplacement establishes the feasibility of retrieval. Packing in the borehole and chemical interaction between the package and the packing, for example, could make retrieval considerably more difficult than emplacement. In other words, retrieval may not be a straightforward reversal of emplacement. Finally, retrieval from horizontal holes has not been demonstrated.
3-28		Figure 3-6 shows 90° pillar corners. In actual practice, corners are always truncated to allow for vehicle turning radii. Subsequent spalling causes further rounding.
3-29	3-7	The means by which these room dimensions were determined needs to be clarified. If a boring machine is used, wall surfaces will not be rough.
3-33	7-11	With the underground constraints as presented, the rope speeds should be minimal (low acceleration and low deceleration). Two waste packages per day does not require a "high-capacity" system.
3-34	10	M.A.N.-GHH Sterkrade (1982) has built at least three hoists with total suspended loads in excess of 300 t. Therefore, the stated maximum value is incorrect.
3-34	11	M.A.N.-GHH Sterkrade (1982) has built at least six tower-mounted hoists with wheel diameters greater than the stated value.
3-34	20-25	The maximum payload given (52.4 t) is about right for existing hoisting systems, but the logic and calculations by which the value was obtained are incorrect. Larger hoists could presumably have been built had there been a need for them.
3-36		The 80-ft by 80-ft pillars shown should give adequate lateral constraint. Deeper burial, which would not materially change the subsurface layout, would position the waste package in a more stable portion of the pillar.
3-37	1-6	Shortening of the waste package would not necessarily require major modifications in the design of the shaft or subsurface facilities. However, Sec. 3.8 is incomplete in that the underground effects of shortening the waste

Page(s)	Line(s)	Comment
		package are not fully evaluated. Moreover, the larger question of what the optimum package is with respect to repository design has not been dealt with. However, other things being equal, the trend in repository design has been toward minimizing the number of emplacement holes. Given this trend, breaking the cladding to get shorter packages will never seem attractive. To defend having more holes, some nonlinearity in thermal and creep response would have to favor lower decay heats per package.
3-37	18-19	This sentence would be clearer if it were revised to read: ". . .the same number of metric tons of spent fuel per package." Because the weight of a PWR assembly is 0.66 t, only in the case of one assembly per package could one reasonably talk about packages per metric ton. Either "tonne" or "metric ton" should be used.
3-37	22-23	See the comment for lines 18-19 above.
3-37	22-25	Shortening the waste package while maintaining its diameter would lessen its weight. If the longer package could be lowered in the shaft without shielding and guided into a case, safety could be increased without shortening.
3-38	25-28	Because of its small thickness, the Zircaloy cladding would not represent much of a barrier if a waste package were breached such that the waste form came into contact with a brine.
3-41	1-4	This paragraph is incomprehensible.
3-41	10-12	The need for buffers in the shaft sump to decelerate waste packages that may "free fall" is not mentioned. However, given NRC requirements for hoisting system safety devices, free fall is highly unlikely.
3-41	21-23	A larger diameter waste package would not provide more shielding if its wall thickness remained the same. The conclusion that the required thickness of the cask shielding could be decreased is therefore incorrect.
3-42	9-24	In the event of breakdown or other emergency associated with the transporter or emplacement machine, recovery of the waste package and transfer to a companion piece of equipment could not be accomplished using the present openings.

Page(s)	Line(s)	Comment
3-42	23-24	It is not clear that minor reductions in room dimensions are what would be considered "significant advantages."
3-42	28-29	A change in layout would not affect the dimensions of the transporter. Actually, the reverse is true.
3-42	30-31	Under no circumstances should the drift size be decreased.
3-43	17-18	There should be no further burdens on safety design.
3-44	1	On the basis of the stated waste receipt rates of 3000 tU/yr and a net weight of 5.64 tU per PWR-12 waste package, a repository would be expected to handle 532 packages a year. This rate works out to about two packages per working day for a five-day week. Doubling the number of packages would not require multiple package hoisting.
3-44	5-11	The drifts are too small as designed and should not be reduced. Pillar stability is a function of the width to height (W/H) ratio. Stable pillars in salt require a W/H ratio of at least four. In the case of horizontal emplacement, a shorter package having the same diameter would not affect room height. Finally, the unfavorable effect on layout resulting from a larger number of packages should be detailed.
3-44	19-20	As discussed in the comment regarding line 1 of this page, doubling the number of packages would have little effect on operations.
3-45	1-4	It is not true that Case 2 offers relatively little advantage. In addition, the overall advantage in using shorter packages may not be small.
3-46		Case 1 would have essentially no effect on the transfer cask and should be scored as "0." Positive effects on repository layout are overemphasized.
4-1	7-11	The phrase "may be excessive" is unacceptable. A smaller and cooler waste package would enhance shaft safety, underground handling, and emplacement in the borehole.
4-4	19-21	Any consideration of spent fuel younger than 10 years out-of-reactor seems odd when much of the existing spent fuel is considerably older than 10 years.

Page(s)	Line(s)	Comment
4-4	22-27	A uniform layer of crushed salt will be difficult to establish, particularly in a horizontal hole. Centralizers should definitely be used, either for constructing an annulus void or before back-filling with salt, if it is possible. Vertical emplacement would facilitate centralizing and salt filling and would provide a much more uniform annular space.
4-6	1-3	While the report states that the reference package design is adequate to withstand horizontal borehole in-pillar stresses, horizontal and vertical emplacement stresses are not compared. The text refers to Sec. 3.4, which again speaks of a "horizontal emplacement configuration."
4-6	24-27	The advisability of using a crawler-type vehicle as the "preferred transportation vehicle" is questionable. Tracked vehicles have a tendency to slide on slick salt roads. Rubber-tired equipment would require less maintenance, have fewer moving parts, generate less noise, and operate at higher velocities.
4-7	7-8	The largest payload of an existing hoisting unit is 52.5 short tons. Although the technology exists to build bigger units, there has been no need.
4-7	14-29	It appears that the waste package is 16 ft long. Page 3-29 states that the "operating envelope dimensions would be slightly less than the 20 x 15 foot design dimensions." In line 7, a height of 13.5 ft is given. Unless vertical emplacement has been ruled out, a minimum room height of 20 ft is recommended.
4-8	8-10	From a hoisting and handling standpoint, a shorter and lighter waste package would be more desirable.
5-1	2-3	Only one recommendation is made. Line 24 also mentions the missing recommendation 2.
5-1	5-10	The recommendation is made without experimental validation, especially with regard to heat transfer within and from the waste package.

Page(s)	Line(s)	Comment

5.1.1 Appendix A

Page(s)	Line(s)	Comment
A-5	15-21	The terms D and d are taken to be both nondimensional and dimensional, which is poor practice. There are at least seven typographical errors in the equations. For example, parentheses are missing from the denominator of the second equation defining D.
A-6	22-27	The equation defining n_{tr} has symbols missing. In the equation on line 27 and in the first equation on the next page, a distance is defined in terms of the dimensionless parameter D.
A-7	10	The equation should read: $QP = (D/2)^2 - OP^2$.
A-8	9, 17, 19	A square root sign is missing from the definition of OV. A summation sign is missing from the equation defining n_{seg}. A plus sign is missing from the last equation.
A-13		The 33,000 value, which appears six times in the headings, is undefined.

5.1.2 Appendix B

Page(s)	Line(s)	Comment
B-2		The analysis in App. B would be easier to follow if the figures had been inserted in the text rather than placed at the end.
B-11	24-28	The last paragraph is not clear. The thermal conductivity used and the temperature to which it pertains should be provided.
B-13; B-14		The sources for the material properties and power-decay characteristics given in Tables B-1 and B-2 should be provided.
B-13		That the thermal conductivity of crushed salt is exactly one order of magnitude less than that of solid salt should be labeled as an assumption. Also, RE/SPEC (1984) gives 425 not 465 J/kg-K for the specific heat of spent fuel.

Page(s)	Line(s)	Comment
B-14		The assumed burnup of the fuel and the source of the data should be provided.
B-15		The meshes used in the calculations should be provided. The text does not indicate whether mesh convergence studies were carried out.
B-17	5-31	More detail is required regarding the "analytical" model, which should be referenced. In particular, it is not shown how well the model represents the physical situation. Finally, given the differences enumerated between the analytical model and the DOT computer code, it is wrong to assume that the results are significant.
B-19	1-14	More detail is required regarding the "analytical" model.
B-19	15-24	The authors note that maximum temperatures are higher for horizontal than for vertical boreholes. However, they fail to note that, for example, for PWR-12 at 30 W/m^2, the vertical borehole value is 11°C higher than that for the horizontal borehole. This crossover phenomenon should be explained.
B-20	25-27	The report states that "two-dimensional results are adequate for initial selection of emplacement mode." This assumption needs to be proven.
B-21	15-17	The statement that "two-dimensional analysis is not conservative" would seem to contradict the statement in lines 25-27 of page B-20. If the analysis is not conservative, one cannot be sure that it is adequate.
B-24	29-32	Such extrapolation may not be valid for all emplacement modes (e.g., multiple packages in long, horizontal boreholes).
B-27	1-4	This paragraph does not make sense.
B-28	9-28	The method for determining the average room temperature should be given. The pillar centerline temperatures at midheight are 5-20°C higher for horizontal emplacement. However, the statement is made that the results at 50 years are insensitive to vertical or horizontal emplacement or to the thermal conductivity of salt because these differences are within the "accuracy band of the model."

Page(s)	Line(s)	Comment
		"Accuracy band" should be defined, and how it is determined should be clear. A temperature difference of 20°C at the pillar centerline seems significant because the temperature there would be on the order of 100°C. With the ambient temperature at 30°C, the temperature increase is about 70°C, which in effect indicates that the calculations are not accurate to within 20/70 = 0.29, or about 29%. This percentage seems rather large in comparison with previous studies that compared calculated and measured temperatures from field studies. Throughout App. B, temperature increases should be given in addition to temperatures.
B-28	26-29	Although the temperatures may not vary significantly, the temperature gradients are not identical. Hence, the distribution of thermal stresses will be somewhat different.
B-31	15-17	This sentence should be revised to read: "This model was used in Sec. B-3 for. . . ."
B-31	25-29	Temperature differences of 8°C are not likely to be significant. Their lack of significance, however, does not make them negligible.
B-37		Some of the R_r values are inconsistent with values given on pages B-39 and B-44.
B-61 to B-65		Figures B-25 through B-29 imply that the borehole would be drilled from the floor of the opening. In reality, it would be at midheight.
B-67 to B-70		Figures B-31 through B-34 show the borehole as connecting at floor level. In reality, the borehole would be at midpillar height.

5.1.3 Appendix C

Page(s)	Line(s)	Comment
C-11	12-18; 23-24	The role of the air gap is overemphasized. The peak radial stress resulting from the analysis is therefore incorrect.
C-12	23-27	Although not explicitly stated, these calculations represent a sensitivity analysis.
C-13	19	The reference to Fig. C-3 should be to Fig. C-1.

Page(s)	Line(s)	Comment
C-14		The density given for air is rather low. The table indicates a yield strength of infinity for salt, which contradicts data indicating that salt creeps irreversibly under even a small deviatoric stress. Also, RE/SPEC (1984) gives 26.08 GPa, not 28.53 GPa, for the bulk modulus of salt. Finally, the footnotes should indicate that T is in degrees Celsius. The following mechanical properties for salt should be used in Table C-2: Creep Limit ≅ 1.0 MPa Yield Limit ≅ 9.0 MPa Shear Strength = $f(\sigma)$ Strain Rate = $f(\sigma,\tau,T)$
C-15		The given creep formulation is not accepted by the rock mechanics community.
C-16		The footnote should indicate that T is in degrees Celsius.
C-18	5-29	See the comments for page C-11, lines 12-18, concerning peak radial stress and the air gap.
C-18	14-19	"Hoop mode" is a misnomer because the packages are not thin-walled.
C-18	18-19	This position is not well supported by the data, which show that the peak radial stress increases exponentially with distance from the top of the canister. Extrapolation of the data indicates that if the calculations were allowed to proceed until the bottom gap closed, the peak radial stress could be as high as 35 MPa, which is almost twice the design stress and equal to the failure stress (see Sec. C.3.2.1).
C-18	20-23	The impact study seems to assume that the package will be centered in the hole. The heater tests at Avery Island indicate that the gap may fill with recrystallized salt.
C-21	3-5	The relationship is approximately linear only if the thickness of the annulus is small compared with the diameter of the waste package. Fifty percent, however, is high for the porosity of the backfill.

Page(s)	Line(s)	Comment
C-21	13-14	The report states that "two-dimensional analyses are adequate to bound the mechanical response." This statement is an assumption and should be stated as such.
C-22	23-25	To have such an air gap requires some way to hold the waste package up. Otherwise, the package will sit on the bottom of the slot.
C-24; C-25	27; 1	The elastic limit of salt for both compression and tension is so low as to be almost nonexistent. This fact is observed here, but not during evaluation of the air gap.
C-25	17	The term "closure" is preferable to "convergence" to avoid confusion with "convergence" of the iterative modeling scheme.
C-26	15-16	Depending on the emplacement method used, the porosity of the backfill could be as low as 20-25%.
C-26	19-24	The pressure of the consolidating crushed salt on the solid salt should be considered here because it could affect the closure.
C-26	28-29	The meaning of this sentence is not clear.
C-27	3-19	The temperature at which the plastic yield stress for the package material is applicable should be given, as should the allowance (if any) made for corrosion of the package material. A reference should be given for the source of the material yield strength.
C-28	13-21	Insufficient detail is given for the analyses. In particular, the reference should indicate on which pages of Baumeister the analysis is found.
C-28; C-29		The derivations of the equations in Secs. C.3.2.2 and C.3.2.3 are not adequately documented. The discussion needs to be expanded.
C-29	18-29	It is not clear from the analysis presented that the cited effects have indeed been considered. A more explicit discussion is required.
C-30	5-6	The repository floor depth is given as 792 m, which is inconsistent with the depth of 784.8 m given on page B-36, line 2. The greater depth, however, is conservative.

Page(s)	Line(s)	Comment
C-30; C-31	18-31; 1-6	The beneficial effect of the air gap is overemphasized.
C-31	3-4	This analysis is inadequate and needs to be redone.
C-32	2	This equation seems nonsensical. It sets the stress rate equal to an elastic modulus times the steady state strain rate that is derived under creep conditions where the stress rate is zero by definition. Then, it appears that the equation between the two equal signs is not used anyway because the stress rate is determined by integrating the temperature rate, which is calculated from the solution for an infinite line source. The text does not give the values used for the bulk modulus or the coefficient of thermal expansion of the salt or even a reference.
C-32	12-15	One cannot obtain the stress relief due to creep by multiplying the steady state creep rate by an elastic constant. If the material is creeping, elastic constants are meaningless. What is underestimated is the amount of deformation that has occurred.
C-33	7-8	Because Carslaw and Jaeger present many solutions, a more specific reference is needed.
C-33	10	The "small computer program" is not adequately documented.
C-37	8-9	The reference to Fig. C-34 should apparently be to Fig. C-38.
C-38		The waste package thermal power used should be given.
C-39		The initial horizontal stress component should be given. The excavation sequence of the emplacement holes was apparently not simulated.
C-69		Part (a) is reversed. No indication is given whether mesh convergence studies were conducted. These meshes do not seem to provide adequate detail.

5.1.4 Appendix D

D-4	3-8	There seems to be a finite difference between "this documentation has been included here to show the

Page(s)	Line(s)	Comment
		tentative selection. . ." and "this appendix is not meant to substantiate the emplacement mode selection. . . ."
2	2-3	It is wrong to assume that backfilling will be "close-coupled" (whatever that means) with emplacement. Rooms may be required by NRC to be open for a substantial period.
2	13-15	This assumption is invalid. Retrieval of representative packages may be required for quality assurance purposes.
3	29-33	The technical specialties of the members of the group are not given; therefore, it is difficult to judge whether they are sufficiently qualified to make such relative ratings.
5	24	If only one to two waste packages are to be stored per day, it is difficult to understand why the authors would want to maximize the excavation rate. This goal might be desirable during initial construction but not during the operating period. Excavation or mining equipment costs will be one of the less important costs of the repository.
12	6	The first adverse consequence from alternative 4 also applies to alternative 5. Also, from a shaft and underground-handling standpoint, there is nothing negative about smaller packages. In fact, they have many advantages. The seriousness of more packages is "low" not "medium."
12	15-17	A repository having a "great amount of brine" will be a poor repository site.
12	18	"Horizontal on the floor (across)" would be a much worse configuration than "horizontal-on the floor in the corner." The maximum amount of movement of the floor will occur in the center of the room. Such movement could change the position of the package. If plans call for reopening rooms with a borer, continuous miner, or other similar device, encountering a waste package would be disastrous.
13	2-4	It is not clear how sleeve deformation and brine collection are related.
13	6	The ratings should be "low" and "high" to be consistent with those for alternative 7 on page 12.

Page(s)	Line(s)	Comment
13	7-11	This statement is not clear.
13	24	Same comment as for page 13, line 6. Also, alternative 7 (horizontal-sleeved) evidently involves emplacement in a pillar. While retrieval will be particularly difficult with a bent sleeve, all retrieval will be delicate -- much more delicate than from vertical boreholes.

5.1.5 Appendix E

Page(s)	Line(s)	Comment
1	25	There is no requirement for a 12% grade in the repository layout. This requirement is unnecessarily restrictive and automatically eliminates rail transport. Most salt mines have level entries and drifts. In a few special cases, tunnels are inclined.
1	26-27	Pot holes have never been a problem in salt mines. Roads are generally constructed by spreading a layer of fine salt. This layer is leveled with a motor grader and compacted by traffic. The only real road problem is that traffic causes the salt surface to become slick. Practically all mines use rubber-tired haulage. To keep the vehicles from sliding, the road is scarified with a motor grader. Shovels with crawlers have to be helped along by rubber-tired vehicles.
1	33-34	It is difficult to visualize the transporter damaging the roof. Again, the pillar would suffer no real damage if the transporter were to run into it. However, a new transporter might be needed.
2	14	The 12% grade for an unloaded vehicle is unnecessarily restrictive.
2	24; 27	It is not clear why "minimum mean time to repair" is weighted higher than "maximum reliability." Short repair time means nothing if the time between repairs is also short.
3	4-6	The 12% grade is unnecessary.
3; 4	37; 1-3	Floor heave is a function of many factors, including the strata underlying the pillars. During emplacement of waste

Page(s)	Line(s)	Comment
		packages, floor heave should not be a problem. Road maintenance should be routine and should not cause any problem for the transporter.
4	12-15	Minimizing roadway wear on the main corridor caused by the transporter should not be of concern.
4	16-18	Heavy bearing pressures should not lead to deep cracks and other deformities.
5	3-13	On the basis of numbers given to the various alternatives, options were eliminated in prescreening that are not given here.
5	15-21	Monorails, overhead or otherwise, are not common in mines.
5	24-26	The only wheeled vehicles with "skid steering" are the little "AmphiCat" all-terrain vehicles.

5.1.6 Appendix F

Page(s)	Line(s)	Comment
F-4	1-17	It is inconceivable that shielding could be eliminated from the waste hoist. No shielding would require placement of hot cells underground and isolation and remote-control operation of all activities in the waste shaft and its stations, including transfer of the waste package to and from the shaft conveyance. Decision analysis to defend a shielded transfer cask is therefore totally unnecessary.
1	12-14	The purpose of shielding is worker protection everywhere in the facility, not just in the shaft.
2	7-9	The uncertainties in repository design should be explained in detail.
2	21-22	No workers will be in the shaft during hoisting operations.
2	23-24	In the case of a malfunction, a 12-t package will be easier to handle than a 42-t package.
3	17-34	The "seriousness" in both cases is "high."

Page(s)	Line(s)	Comment
F-5	5	The total suspended load of the production hoists for the Cathedral Bluffs oil-shale mine is greater than 300 short tons. The total suspended load of the hoist at Consolidation 3 Mine in West Germany is 340 t (M.A.N.-GHH, 1982).
F-5	6	The largest wheel diameter installed by M.A.N.-GHH (1982) is 7.0 m at the Pigeot mine in France.
F-5	12	The assumption that conveyance weight = 0.75 times payload applies to drum hoists, not friction hoists. With friction hoists, the ratio will vary to achieve an acceptable T_1/T_2 ratio and an acceptable tread pressure. As it happens, 0.75 is acceptable for a depth of 3000 ft.
F-5	14	The D_{wheel} to D_{rope} ratio of 120 is unnecessarily restrictive. Ontario Mining Regulations (accepted standard for hoisting system design) require a ratio of 100 for locked coil rope. This ratio was also the U.S. Mining Safety and Health Administration standard prior to 1983, when the requirement was removed.
F-5	16-19	This calculation is superfluous because the assumption as to maximum total suspended load is incorrect. Furthermore, the equation itself is incorrect, for the total suspended load also includes the effective equivalent weight of the hoist wheel reduced to rope diameter. M.A.N.-GHH Sterkrade (1982) indicates that for its hoists, total suspended load equals $2T_1$.
F-8	10-18	This calculation does not make sense. The counterweight is normally sized so that its weight is equal to the cage weight plus 0.5 times the cage load. Using the 0.75 factor assumed, T_2 equals 1.25 times payload plus rope weight, or in this case 122.25 short tons. This result gives tension ratios of 1.31 and 1.24 for the unloaded and loaded cases, respectively.
F-9; F-10		These calculations are superfluous because the assumption for maximum total suspended load is incorrect.

5.1.7 Appendix G

G-11	19-25	If the drifts are reconsidered from an operational standpoint, transporters should not present problems. The

Page(s)	Line(s)	Comment
		total allowable weight of the transporter should be gauged from those used at successful commercial salt mines.
G-15		This logic diagram should appear in the main body of the report.

5.2 COMMENTARY ON *EVALUATION OF WASTE EMPLACEMENT MODE*

v	19-24	The use of ex post facto qualitative screening calls into question the validity of the rankings developed using the Kepner-Tregoe methodology.
vii	1-6	When ex post facto judgment can eliminate options selected by the decision methodology, the decision methodology is rather weak.
vii	16	Alternative 8, which received the second highest score, was later eliminated by introducing the subject of cost, which had previously been discarded on pages C-8 to C-10.
vii; viii	28; 1-10	Cost is not and has never been the primary criterion. The argument for rejecting the "best" alternative is therefore unacceptable. Furthermore, the added cost may be only a fraction of the total repository cost.
viii	11-18	Any difficulties should be reflected in the Kepner-Tregoe ranking, rather than identified ex post facto.
viii	19-33	The decision analysis method should have explicitly accounted for potential difficulties.
1-1	17	The terminology "DOE Generic Requirements" should be explained and referenced.
1-1	27-29	This sentence appears to question the competence of the Project Salt Vault engineers.
1-1; 1-2	31; 1-2	According to people who were involved in the Office of Waste Isolation (Oak Ridge) work, this statement is completely false.
1-2	6-7	There is a very good basis for selecting vertical over horizontal emplacement.

Page(s)	Line(s)	Comment
1-2	18-19	With respect to the objective of the study, the meaning of "most desirable" is unclear. The parameters with respect to which the emplacement mode is to be "most desirable" (e.g., cost, schedule, or safety) are not stated.
1-3	12-14	The group of experts listed in App. D of the impact study does not include any recognized authorities in rock mechanics, hoisting, or geology.
1-3	16-18	Advantages and disadvantages should be incorporated into the decision-analysis process.
1-3	21-25	Full documentation is a licensing requirement, not a desirable action.
1-3	25-28	If cost is not the sole criterion, then it should not be used to disqualify options in a postoptimality analysis.
1-4	3-24	The entire discussion is simply an elaborate attempt to gain reader acceptance of the Kepner-Tregoe methodology through the principle of social proof. It is not clear whether any alternatives to the Kepner-Tregoe method were considered. This particular method was apparently chosen for convenience rather than for its rigor.
1-5	11-27	Group decision making tends to be dominated by those with dominant personalities, and minority opinions may not receive adequate consideration. Also, the approach may be easily understood, but that does not mean that it is rigorous or that it results in a correct decision.
1-5; 1-6	28-31; 1-8	The Kepner-Tregoe method is just as subject to bias as any other decision technique. This weakness is especially evident in the way it was applied in the draft position paper.
1-6	31-34	It is true that structured decision analysis would have such results; however, the method used here would not minimize bias.
2-1	5	The word "retrieval" should be inserted after "operation."
2-1	15-16	A sleeved, horizontal borehole is actually the first choice according to the Kepner-Tregoe ranking.

Page(s)	Line(s)	Comment
2-1	15-30	Retrieval requirements are mentioned without telling the reader what they are. Also, as previously noted, the statement that "the need for retrieval is considered of low probability" seems to ignore licensing. Finally, although sleeves may not be required for retrievability, retrievability should have been discussed and analyzed.
2-2	1-3	The criteria for determining "an acceptable horizon" are not given.
2-2	12-14	The entries for horizontal emplacement may not necessarily be smaller. They may simply have their larger dimension in a different direction.
2-2	15-17	Stability of entries does not depend on the height of the walls -- it does depend to some extent on the span-to-height ratio. The strength of pillars depends on the pillar width-to-height ratio. Pillars having ratios greater than four are stable, even in salt. Because this ratio is exceeded for the pillars in the given repository design, the height is not important for pillar stability either.
2-2	18-21	If the weight were supported, then the only forces to be overcome in removing a package would be frictional. In the case of holes at any other orientation than horizontal, all or part of the weight would have to be overcome in addition to any frictional forces. However, if waste packages were to be retrieved by overcoring, this advantage of reduced tension would no longer apply. In any case, the "rope pull" required has nothing to do with the amount of damage (if any) done to the package during retrieval. Furthermore, because steel is far stiffer than salt, it is difficult to imagine how the package could be damaged during retrieval.
2-2	22-25	The choice of an emplacement mode cannot be justified by what is being done at other sites.
2-2	26-28	Short, horizontal boreholes are no better than vertical boreholes as far as potential stress levels on the package. Actually, pillar stress is likely to be greater than floor stress. Also, horizontal boreholes would not necessarily be located in areas of less relative movement. In both cases, movement is likely to be toward the room. The only case where more movement is likely to occur in the floor is the

Page(s)	Line(s)	Comment
		case in which floor heave occurs. Floor heave is generally controlled by planes of weakness in the salt, which should be avoided to the degree possible. No particular problems have been observed during full-scale heater tests at Avery Island or Project Salt Vault in the vertical mode, but the horizontal mode has yet to be demonstrated.
		Because temperature affects the creep rate, considerable salt movement will occur in the vicinity of the package no matter where it is located. Furthermore, the assumption that wall deflections are less than those in the roof and floor requires that the primitive horizontal stress be smaller than the primitive vertical stress. This relationship may not be true in salt. Both hypotheses in item 7 need to be analyzed and proved.
2-3	1-2	The "thermal response" should be identical if the same thermal properties were used. Because pillar temperatures will be higher for the horizontal mode, the temperature distributions cannot be identical. At this point, the draft position paper has not stated how deeply into the pillars the waste package will be placed or how large the rooms will be. In addition, the reader does not know on what basis these decisions were made (e.g., weight given to factors such as cost, development of new equipment, and ease of retrieval).
3-1	3-5	References should be given for the previously published studies that are mentioned.
3-2	1	The project criteria should be explicitly stated.
3-3 to 3-9		It is totally unnecessary to identify so many obviously unacceptable alternatives. Only 17 alternatives are discussed in the impact study.
3-9	5	The words "was eliminated" should be changed to "was not eliminated."
4-1	2-4	The text should indicate what is being evaluated.
4-1	6	Certain details that would make the draft position paper more readable should be given, such as the dimensions and weight of the package and the vertical thickness at the Deaf Smith County site.

Page(s)	Line(s)	Comment
4-1	21-22	The first sentence of item 5 should read: "The vertical thickness of the host rock was assumed to be that found in the Cycle 4 Salt of the San Andres Formation at the Deaf Smith County site."
4-2	2-3	If "RE/SPEC (1984)" is still in draft form, it should not be cited.
4-2	9-12	To simply say that "A temperature gradient of 200°C was assumed between the package centerline and package surface" avoids discussion of the status of differences among calculations. Doubts are raised as to whether the complex evaluations can be trusted.
4-4	4	Some state mining acts, notably those of Colorado and New Mexico, contain more stringent regulations than those of the U.S. Mining Safety and Health Administration. It might be advisable for the repository design to meet the most stringent regulations rather than those of the federal agency.
4-5	2-12	The wants are probably not independent. For example, minimizing the volume excavated may also minimize excavation costs. This lack of independence could result in related wants having a total weight in excess of their true importance.
4-6	2-18	Again, some of the factors are related. For example, the first (minimize nonuniform forces) is related to the fourth (maximize stability of emplacement opening).
4-7	1	This criterion (maximize use of proven technology) should not have been dismissed. Equipment does not exist for emplacement in horizontal holes.
4-7	12	It is not clear whether "geologic stability" refers to the stability of the openings in the salt or something else.
4-7	17	This want (maximize far-field geologic integrity during retrieval) should be deleted, as it is irrelevant.
4-7	20	This want (maximize use of proven technology) should not have been rejected. Retrieval from horizontal holes for distances up to 600 ft is not proven technology, for example.

Page(s)	Line(s)	Comment
5-1	20	Insert the word "operational" before "life-cycle."
5-2	20-27	Drilling large, long, horizontal holes has yet to be demonstrated. Emplacing waste in such holes is also untried. Concepts based on long holes have been explored as part of the Basalt Waste Isolation Project and the Nevada Nuclear Waste Storage Investigations, but the equipment for such options exists only on paper.
5-3	15-17	Assigning three significant digits to the weights determined "through the consensus of the group" is inappropriate.
5-3	24-26	This type of scale has obvious difficulties. For example, if there are only two alternatives, the scores will be 10 and 1 even though there may be only a slight advantage to the better option.
5-4	12-14	Retrieval from an unsleeved vertical hole might be difficult if retrieval were a simple reversal of emplacement. This view of retrieval is overly simplistic. If overcoring were necessary, retrieval from an unsleeved vertical hole would be the most favorable alternative. Furthermore, retrieval from vertical holes is a proven concept.
5-4	24-27	Backfilling is assumed to occur before retrieval. The proposed sequence of operations should be summarized.
		Packages will definitely interfere with remining.
5-4	27-30	Retrieval may be considered a low-priority item; however, if it presents severe problems, the alternative in question cannot be a "good" one.
5-5		The vertical concepts score second and fourth under emplacement, with the horizontal placement concepts scoring first and third. The differences are not significant. The vertical alternatives are hurt the most by the questionable low scores under excavation, especially in the case of a sleeved, vertical hole, which scores third on retrieval. The highest score for retrieval is for a long, horizontal hole; this score is not valid.
5-6	6-9	The conclusion that the taller openings needed for vertical holes are undesirable is overemphasized. This bias results in an unreasonably low score for the vertical alternatives.

Page(s)	Line(s)	Comment
5-7	3-6	The sleeve story is incomplete. If the retrieval method is limited as to the size of the package to be recovered, that limit must be one of the waste package criteria. If there is no size limit or if the limit permits, the sleeve could be retrieved with the waste package. Also, if retrieval depends on limited changes in the dimensions of the waste packages, those limits should be identified.
5-9	14-19	Using cost to rule out alternative 7 is unjustified. Cost was not used anywhere else in the analysis.
6-1	15-23	These statements are not justified. The difference in heights is not large enough to make any meaningful difference.
6-1	21	The meaning of "greater entries" is unclear. Perhaps "higher entries" is meant.
6-2		Figure 6-1 should be presented as a bar graph to avoid implying a functional relationship. Also, it would be convenient if page numbers were added to the figure to indicate where each "want" is discussed in more detail.
6-3	13-19	These statements are inaccurate. Room stability does not depend on the height of the walls as much as on the condition of the roof. Wall stability depends on the width/height ratio of the pillars. The pillars in the repository will have a sufficiently large width/height ratio to ensure their stability.
6-4	3-9	The most difficult excavation is for slots in the wall, which would require much hand labor. This alternative would be considerably more difficult than the continuous second pass that might be required for vertical holes.
6-4	20-23	There is no real basis for saying that it will be important at the Deaf Smith County site to observe the horizontal bedding and imperfections in the salt in the entry wall to allow "selection of the best location for the emplacement opening(s)." Such a statement must be grounded in an analysis of the probable stratigraphy at the repository-room horizon. The lithologic log for LSA4 salt from the G. Friemel No. 1 core hole, for example, indicates that imperfections in the salt bedding at the room horizon are most probably insignificant (Fukui, 1984). Assuming an

Page(s)	Line(s)	Comment
		imperfection were significant, the authors should indicate whether the vertical working range of the transporter would permit effective emplacement of a waste package above or below the usual height. The authors should also provide a rationale for determining just how far above or below such an imperfection would be far enough. Indeed, careful analysis of the expected stratigraphy might show that vertical emplacement would present fewer problems than horizontal emplacement. Such an analysis has not yet been done.
6-5	1-10	While less force is required to move a horizontal package than a vertical one, horizontal retrieval has not yet been demonstrated. Retrieval from vertical boreholes has already been demonstrated.
6-5	2-4	This sentence contradicts the scores for the want "Minimize Risk of Package Damage" (emplacement section) as shown on page 6-2 and page 23 of App. C.
6-5	11-15	Other considerations are that the roof spans are equal; therefore, the chance of roof falls is about the same in either case. With horizontal emplacement, the pillars will be weakened by the emplacement holes and the elevated temperatures. It is not clear how long the rooms will remain open after emplacement.
6-5	16-19	The analysis for this want is wrong. Long horizontal holes received the highest score even though no system exists for moving the packages into or out of such holes.
7-1		The major source of material properties in both reports reviewed is "RE/SPEC, 1984," which is a draft report.

5.2.1 Appendix A

A-4	12-27	The transporter should be used to emplace the waste. Transfer of the transfer cask between vehicles or conveyances should be minimized.
A-5	20-21	This procedure assumes that one can drill accurately right to the package and that the pintle on the package can be used to lift it. Both these assumptions are faulty. In the Waste Isolation Pilot Plant design, the annulus cutter is a trepan incorporated into the retrieval barrel.

Page(s)	Line(s)	Comment
A-6	12-20	Same comment as for page A-4, lines 12-27.
A-7	21-22	Same comment as for page A-5, lines 20-21.
A-8		Excavating slots having the indicated dimensions would be quite slow and difficult, and would require considerable hand labor.
A-9	6	Such slots would have to be mined by pick and shovel.
A-9	12	Placing a lot of crushed salt behind the blocks would have to be done pneumatically. It is feasible but not efficient.
A-9	24	It is difficult to visualize how the package would be engaged and transferred to the transfer cask during retrieval.
A-10		The four-foot-high slot would be difficult to excavate, especially at floor elevation.
A-11	4	The room dimensions are different from those given in the corresponding figure. (Discrepancies in dimensions occur in all of the following emplacement mode figures and text.)
A-11	6	Same comment as for page A-9, line 6.
A-11	23	It is not clear how the package would be supported during the horizontal cutting or why the operation is needed.
A-11	24	Same comment as for page A-9, line 24.
A-12		The four-foot-high slot would be difficult to excavate.
A-13	6	Same comment as for page A-9, line 6.
A-13	17-23	Retrieval would have to be by remote control, as it would be difficult to provide adequate shielding.
A-14		Same comment as for Fig. A-3, page A-10.
A-15	21-25	Same comment as for page A-13, lines 17-23.
A-15	24	Same comment as for page A-11, line 23.

Page(s)	Line(s)	Comment
A-17		Excavation of these slots would be very time consuming -- even more so than the second pass that might be required for vertical emplacement in the floor.
A-18	19-23	Same comment as for page A-13, lines 17-23.
A-20	9	NRC will not accept immediate backfilling.
A-20	19-20	Cutting slots around the package may not be as easy as it sounds.
A-22	9	Same comment as for page A-20, line 9.
A-26	11-12	Same comment as for page A-20, line 9.
A-26	16-22	It is not clear how reexcavation of a completely backfilled room would proceed. If full-height remining is contemplated, with the new roof at an elevation nine feet below the old roof, then the packages would be intercepted, which would be hazardous. In the case of a partially backfilled room, reexcavation to the original floor could also result in interception of packages.
A-28		Cutting these transverse slots could be a difficult, time-consuming operation.
A-29	12-13	Same comment as for page A-20, line 9.
A-29	19-21	Same comment as for page A-26, lines 16-22, except that remining a partially backfilled room is to occur at a depth one foot below the original floor. The packages would interfere with continuous miner operation.
A-32	11-12	Same comment as for lines 12-13, page A-29.
A-32	17-19	Same comment as for page A-26, lines 16-22.
A-35	16-22	Supports under the package to keep it from resting directly on the sleeve are not mentioned. Furthermore, the means used to place the packing is not specified. Finally, thermal analysis indicates that backfilling with crushed salt, rather than leaving an air gap, is unwise.
A-36	1-13	This retrieval method will not be practicable if the pintle has corroded. Overcoring would be preferable, but alignment may be difficult in any case.

Page(s)	Line(s)	Comment
A-36	6-7	It is not clear how the package will be supported during this operation.
A-37	15-21	Same comment as for page A-35, lines 16-22, but replace "sleeve" in first sentence with "hole bottom."
A-37	28	This option does not include a hole sleeve.
A-38	1-13	Same comment as for page A-36, lines 1-13.
A-40	10-12	This drilling system has been suggested, but no prototype machine exists. Furthermore, if something were to happen to the machine deep in the hole, it would be impossible to get to it.
A-41	15-16	It is not clear how the backfill beyond the first package will be removed.
A-41	19-22	It is risky to assume that the pintle will be intact enough to grapple. Overcoring is not practicable in a long, sleeved hole. Thus, this option has problems with regard to retrievability.
A-42	25-26	It is not clear how the package will be supported during backfilling, nor is it clear how the backfill will be placed.
A-43	11-13	If a drift is to be excavated parallel to the storage hole for every storage hole, retrieval will be a costly, time-consuming process.

5.2.2 Appendix C

3	24-30	Assuming a peak package surface temperature of 175°C and a maximum package heat load of 6.6 kW implies that areal thermal loading is a variable. The Kepner-Tregoe analysis may not have placed enough emphasis on this aspect, which affects the amount of excavation required and its safety and cost.
10	9	Maximizing the use of proven technology should have received more emphasis. If retrieval cannot be demonstrated, then NRC will assume that the performance objectives in 10 CFR 60 cannot be met and will not grant a license.

Page(s)	Line(s)	Comment
13		Table C-2 shows a clear bias against vertical emplacement, especially in the case of excavation. These low scores are unwarranted, especially if one considers the relatively high scores given to the slot alternatives. Excavating the slots would be difficult. Furthermore, retrieval from long, horizontal boreholes would not be easy. The score for alternative 8 (the highest for retrieval) is not merited.
14	20-22	It is difficult to understand how the package could be damaged during emplacement, especially if the borehole allows for a several-inch-thick annulus.
16	29-32	The justification for doing away with sleeves is totally inadequate. Cost has been considered so superficially in the analysis that it cannot be used to justify any decision.
16	39-42	If package and packing placement will cause problems in a long borehole, these problems should have been reflected in the emplacement scores. Such problems appear here almost as an afterthought.
17	5-24	These considerations should have been reflected in the scores. That high-scoring alternatives can be so easily dismissed after the more formal decision analysis does not inspire confidence in the method.
19		Several of the rankings in Table C-3 are patently incorrect. For example, vertical boreholes score worst under "maximize ease of excavation," when deep slots are considerably more difficult to excavate. It is not clear why the scores are not identical for all of the alternatives for the "maximize safety" and "maximize stability" wants. There is not enough difference between the alternatives in these areas to justify the wide variety of scores.
20	1-19	There is no real difference among any of the alternatives from the standpoint of worker safety.
21	1-12	There is no real difference as to stability for any of the alternatives during the preemplacement stage. It is simply not true to say that taller openings are less stable, at least not when the difference is only five or six feet.

Page(s)	Line(s)	Comment
21	30-31	Excavating shielded slots will be considerably more difficult and time consuming than a second pass along the full length.
23		It is not clear why alternatives 8 and 8A score lower than alternatives 7 and 7A under the want "maximize radiation protection for workers."
		In terms of maximum flexibility to vary package spacing, it is not clear why alternative 2 is rated low (the long dimension of the slot is not "parallel" to the entry wall) and why alternative 3C scores higher than alternatives 3 and 3B.
28		In terms of maximum ability to control contamination, it is not clear why alternative 8A does not score as low as alternatives 1 and 7A. Furthermore, alternative 1 should not be scored so low.
		In terms of maximum near-field geologic stability, it is not clear why alternative 3C does not score lower than alternatives 3 or 3B. Furthermore, in-room storage should score lower than vertical boreholes.
		The scores for "maximize far-field geologic integrity" violate a basic scoring assumption of the Kepner-Tregoe method since no score of "1" was awarded.
29	8-11	Vertical emplacement without sleeving is not the worst case. Retrieval from a long, unsleeved, horizontal borehole is undoubtedly the worst case.
29	31-35	This conclusion is completely untrue. A long, unsleeved, horizontal borehole is the worst case.
30	7-12	The vertical emplacement modes are not the worst. The alternatives with the packages laid on the floor are the worst.
30	26-28	The long, sleeved, borehole does not provide the simplest retrieval. Emplacement in such long holes has not been demonstrated.
30	33-36	The low rating of the vertical hole is unjustified.
31	9-17	The far field (region outside thermal and stress effects) will not be affected by retrieval, regardless of the emplacement option.

Page(s)	Line(s)	Comment

5.2.3. Appendix D

Page(s)	Line(s)	Comment
D-1		Explanations should be provided for the abbreviations listed in the column headed "Source."

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APPENDIX A

U.S. DEPARTMENT OF ENERGY LETTER REQUESTING PEER REVIEW

Department of Energy
Chicago Operations Office
Salt Repository Project Office
505 King Avenue
Columbus, Ohio 43201-2693
Commercial (614) 424-5916
F.T.S. 976-5916

October 21, 1985

Wyman Harrison
EES-362
Argonne National Laboratory
9700 South Cass Avenue
Argonne, IL 60439

Dear Dr. Harrison:

SUBJECT: ANL PEER REVIEW: SRP WASTE EMPLACEMENT MODE

Reference: Fluor report, Draft Position Paper for Evaluation of Waste Emplacement Mode, August 23, 1985. Fluor report, Waste Package/Repository Impact Study, September 27, 1985.

The above documents were given to you in your meeting of October 17, 1985 at SRPO to address the scope of a review ANL is now being requested to perform regarding horizontal versus vertical emplacement of waste packages.

It was agreed that the review would focus around Chapter 6 of the Draft Position Paper which draws comparisons of horizontal and vertical emplacement. The review should consider:

- o The completeness/appropriateness of the evaluation criteria, i.e., could there be additional criteria which are important and which are affected by the choice of horizontal versus vertical.

- o The evaluation rationale for and the relative ranking between horizontal and vertical for each of the criteria.

- o The identification of any other considerations which should be included in the evaluation of horizontal versus vertical along with a bases/rationale and an assessment (if possible) of the effect on the rating of horizontal versus vertical.

- o The review should consider the Deaf Smith site only.

- o A review of the Kepner-Trego decision methodology should not be undertaken at this time.

W. Harrison
Page 2

A draft report of the review findings is to be submitted within 45 days (from review start). ANL will, following submittal of the final review report, interact with SRPO and its contractors to develop clarifications, responses, and dispositions. Also as agreed, you will notify SRPO of the need to attend your core group meeting (1 day only) to assist in clarifying any questions raised by your reviewers. The notification should be a minimum of one week in advance of the meeting.

For questions, please contact K. Robinette of my staff.

Sincerely,

RCWunderlich

R.C. Wunderlich
Deputy Project Manager
Salt Repository Project Office

SRPO:DKR:max:9230B

cc: S. Basham, ONWI
J. Fitch, Fluor/Cols

ST# 038-86

APPENDIX B

CONCURRENCE SHEET

APPENDIX B

CONCURRENCE SHEET

I concur that the Argonne National Laboratory report on Fluor Technology, Inc.'s final report entitled *Waste Package/Repository Impact Study* and draft position paper entitled *Evaluation of Waste Emplacement Mode* fairly represents my comments, where incorporated, to the peer review panel.

Thomas R. Bump	Joseph S. Busch
Larry E. Fischer	Douglas F. Hambley
Wyman Harrison	Charles H. Jacoby
Lyle D. McGinnis	Dennis Z. Mraz
James E. Russell	Ronald G. Whitfield

APPENDIX C

ACTION TO BE TAKEN ON THE ARGONNE PEER REVIEW PANEL RECOMMENDATIONS AND PAGE-BY-PAGE COMENTS

APPENDIX C

ACTIONS TO BE TAKEN ON THE ARGONNE PEER REVIEW PANEL RECOMMENDATIONS AND COMMENTS

ACTION STATEMENTS IN RESPONSE TO THE ARGONNE RECOMMENDATIONS

Recommendation	Action Statement
1	The waste emplacement mode assessment will be reevaluated using a decision-analysis methodology of the Harvard-MIT type. During this reevaluation, the want attributes will be reassessed as well as the ranking of each emplacement mode with regard to the selected want attributes.
2	During future waste emplacement mode evaluations, the importance of the want "ability to locate the package horizon" will be reevaluated in relation to the other wants. As discussed below, the probable stratigraphy at repository depth is such that either vertical or horizontal emplacement can be accommodated. In addition, analysis of the core log of the J. Friemel No. 1 well (Hovorka et al., 1985) indicates that the options for both modes are limited by stratigraphic constraints on room locations.

Although 112 and 116 mudstone seams, respectively, have been identified in LSA4 salt in the G. Friemel No. 1 and Detten No. 1 wells, it is apparent that LSA4 contains relatively thick, nearly pure salt zones that can be correlated over fairly wide areas (Hovorka et al., 1985, Plate 16). In the J. Friemel No. 1 well (Hovorka et al., 1985, Plate 1), for example, clastic interbeds or laminae do not occur uniformly throughout LSA4; indeed, some zones are relatively free of them. One such section, which spans zones 11-15 (-2640 through -2656 ft), has no clastic interbeds. A second example comprises zones 5-7 (-2671 through -2689 ft) and the upper two to three feet of zone 4); it has six scattered mudstone laminae, of which the two thickest are 5 mm thick. Each of these sections contains only small percentages of either anhydrite or chaotic mudstone-halite rock.

If it is assumed that vertical emplacement of waste packages requires a depth below the repository floor of 16-18 ft, then one or both of the above sections could be acceptable. This scenario also requires that the rock overlying one or the other of the two halite zones be suitable for room development. If a room height of about 24 ft is necessary for vertical emplacement, it would seem that the LSA4 interval between -2640 and -2689 ft (a total of 49 ft) would be suitable. The room roofs would be in essentially clean halite, and clean halite sufficient to permit vertical waste-package emplacement would occur beneath the room floors. There

Recommendation	Action Statement
	would, in addition, be 75-80 ft of LSA4 above the roofs of the repository rooms and about 40 ft beneath the bottoms of the waste containers.
	For the case of horizontal waste-package emplacement, nominal room height is taken as 15 ft, and clean salt amounting to 15 ft for the ceiling beam and 10 ft for the floor beam is assumed necessary. The most suitable location of such a 40-ft zone, again referenced to the LSA4 stratigraphy exemplified by the J. Friemel No. 1 core, would be in the section from -2640 through -2680 ft. Here, the ceiling and floor beams would be in essentially clean halite, and the room walls would have only one mud layer 10 mm thick near floor level. This section is essentially the same stratigraphic interval found suitable for vertical emplacement.
	There seem to be only two other possibile room locations for the horizontal emplacement mode. The first would be in the -2704- through -2720-ft interval. The disadvantage here would be that the ceiling beam would contain 13 mud layers that range from 2 to 160 mm thick. The second would be in the -2599- through -2614-ft interval. Although the rooms at this interval would be in relatively clean salt, the ceiling and floor beams would contain mud layers that might be unacceptable.
	The foregoing vertical and horizontal emplacement scenarios will be among those examined in the formal decision analysis planned for the revised report. Also to be evaluated in that analysis will be (1) the effects, where known, of nonsalt interbeds and chaotic mudstone-halite layers on waste-package performance and (2) the significance of the want "ability to locate the package horizon" in view of the limitations on horizontal waste-package emplacement dictated by the vertical working range of the transporter.
	Since the far field is by definition beyond the thermally influenced region of the repository, and since stress redistribution resulting from openings only extends about 500 ft or less into solid material, the want "maximize far-field geological integrity during retrieval" will be deleted from the list of most critical wants.
3	Want objectives regarding cost and use of present technology will receive more emphasis in the revised position paper.
4	The sentences on pages 1-1 and 1-2 of the draft position paper stating that "no thought or study was given. . .performance of the site" and "subsequent salt repository designs. . .without further evaluation" will not appear in revised versions.
5	Appendix E and lines 8-17 of page 1-4 of the draft position paper will not be included in revised versions.

Recom-mendation	Action Statement
6	Formal decision analysis will be used in the reevaluation of waste emplacement modes.
7	The section covering hoist design will be rewritten to emphasize that the evaluation is based on the size of hoist installations in service in the United States and that the use of European technology would permit the design of considerably larger systems.
8	Stress-relief room layouts will be reexamined to determine whether there are potential benefits for a repository.
9	It is agreed that DOE requires the repository to be capable of accepting five-year-old spent fuel (Roy F. Weston, Inc., 1984). It is further agreed, however, that since DOE has specified disposal to be on an "oldest-first" basis, the age of the fuel disposed of in the repository will generally be considerably older than 10 years out-of-reactor. These points will be clarified in subsequent revisions.
10	Results of analyses for the two-element layered model will be compared with results for a salt unit of semi-infinite dimensions.
11	Revised versions will state that the results of creep analyses must be considered tentative until validated by in situ measurements.
12	More-detailed calculations related to peak radial stresses on the waste package will be performed, including calculations that incorporate inhomogeneities.
13	Revised versions of both documents will be carefully edited, with close attention paid to correct spelling.

ACTION STATEMENTS CONCERNING THE ARGONNE COMMENTS IN THE MAIN TEXT

Section	Paragraph	Action Statement
2.1		The adequacy of the want criteria and the validity of the scoring for the various waste emplacement alternatives will be reexamined during the upcoming detailed evaluation. It is agreed that having a must criterion for using reasonably available technology does not indicate the relative attractiveness of the various waste emplacement alternatives

Section	Paragraph	Action Statement
		with respect to this requirement. Since the use of reasonably available technology may be crucial to licensing with regard to both emplacement and retrieval, and since the different alternatives have differing abilities to meet this requirement in both cases, it is agreed that the want criterion "maximize use of proven technology" will receive greater consideration in future evaluations.
2.2		The appropriateness and relevance of the want criteria will be reviewed during the formal decision analysis to be undertaken.
3.1	1	It is agreed that the waste hoist calculations in App. F of the impact study demonstrate that the anticipated combined weight of the waste package and transfer cask is within the limits of current hoisting practice. The appendix will be rewritten to indicate that the "maximum" parameter values given are typical of large installations in the United States although larger installations exist. In addition, the revised version will clarify that the suspended load used in the calculations is the static suspended load rather than the dynamic "total suspended load" that is used in motor horsepower calculations.
3.1	2	It is agreed that the calculations in App. F of the impact study will be done to emphasize that the value of 0.75 times the payload for the conveyance weight is an approximation satisfactory for a first-trial calculation and that the actual conveyance weight would be chosen to give a satisfactory T_1/T_2 ratio.
3.1	3	It is agreed that the iterative approach used in the calculations in App. F of the impact study has some benefits. However, use of the formula given by Argonne National Laboratory (ANL) would provide the *minimum* acceptable rope diameter, provided that the T_1/T_2 ratio requirements are met. The following approach will therefore be adopted in the revised App. F: (1) select the T_1/T_2 ratio, (2) determine the required conveyance weight based on the necessary safety factor, (3) determine the rope diameter, and (4) recalculate the conveyance weight using the next larger standard rope size. Steps 3 and 4 will be repeated until an acceptable value is found.
3.2		Consideration will be given to the use of stress-relief techniques in the design of the repository.

Section	Paragraph	Action Statement
3.3		The revised impact study will clarify that DOE requires that the repository be able to take small amounts of five-year-old spent fuel (Roy F. Weston, Inc., 1984). It will also acknowledge that much of the waste emplaced in the repository will be considerably older than 10 years out-of-reactor.
3.4		The stratigraphy used in subsequent thermal analyses will be based on the stratigraphy in the J. Friemel No. 1 well. Lumping of the stratigraphy will be carried out in a manner consistent with the conditions stated by ANL.
3.5	1	The revised impact study will distinguish between the average value for thermal conductivity used for three-dimensional models and the temperature-dependent relationship used for two-dimensional models. The revised version will state that the average value of the thermal conductivity used for the three-dimensional analyses was 4.7 W/m-°C, which corresponds to a temperature of 84°C.
		The revised impact study will state that the conductivities are higher than the values cited in the Deaf Smith environmental assessment but are substantiated by data from the J. Friemel No. 1 and Detten No. 1 wells, as reported in Durham et al. (1983). It will also state that nonsalt strata are not included in the three-dimensional analyses.
		The sensitivity of results to variations in the thermal conductivities and in the modeling of nonsalt stratigraphy will be discussed in the revised impact study.
3.6		Appendix C of the impact study will be revised to clarify that the computer codes treat yielding and creep as separate phenomena and that a Mohr-Coulomb yield criterion is used because materials (other than salt) that obey that yield criterion (and do not creep) are present. Table C-2 will also be changed to eliminate this confusion. In addition, a paragraph will be added to App. C that puts the current status of creep modeling in perspective.
3.7		The calculations to determine the effect of the air gap will be reevaluated.
3.8		The statements on pages 1-1 and 1-2 of the draft position paper that read "no thought or study. . .long-term performance of the site" and "subsequent in designs adopted the vertical emplacement configuration. . .without further evaluation" will

Section	Paragraph	Action Statement
		not appear in revised versions. The revised document will indicate that a need to reevaluate the mode of emplacement was discerned and that that need provided the impetus for the study.
4		The emplacement mode alternatives will be reexamined using a formal decision-analysis procedure of the Harvard-MIT type. It is agreed that the uncertainty issue can be better addressed using such procedures than by using the Kepner-Tregoe methodology. Cost will be addressed as an attribute rather than as an adverse consequence.
4.1		In the reevaluation of the waste emplacement mode decision, objective or "natural" scales will be used wherever possible. Otherwise, carefully constructed scales accompanied by complete explanations of their meanings will be used. A different method will be used to determine the criteria weights.
4.2		Formal decision analysis will be used to address uncertainty. If appropriate, optimistic, pessimistic, and most likely scores will be given for the various criteria for each emplacement option.
4.3		During the reevaluation of the waste emplacement mode decision, differing opinions will be addressed and their effects determined through sensitivity analysis.
4.4		In the reevaluation of the waste emplacement mode decision using formal decision analysis, cost will be considered in the tradeoff analysis along with other factors (i.e., as one attribute in a multidimensional utility function). Thus, there should be no need for treating cost through an adverse consequence analysis.
4.5		It is agreed that App. E of the draft position paper is inappropriate; it will not appear in subsequent versions.

ACTION STATEMENTS FOR PAGE-BY-PAGE COMMENTS

Waste Package/Repository Impact Study

Page(s)	Line(s)	Action Statement
iv	17-18	A sentence will be added indicating that the corresponding waste package containing boiling-water-reactor assemblies would generate less heat and was therefore not considered.

Page(s)	Line(s)	Action Statement
x	3-4	No action is necessary.
x	7-10	In the revised impact study, the sentence will be changed as suggested. To avoid potential clearance difficulties caused by creep closure, subsequent studies of horizontal emplacement will call for rooms 24 ft wide.
x	18-19	The paragraph will be rewritten to indicate that the payload of 52 t was chosen to be consistent with the expected combined weight of the waste package and transfer cask and that hoisting systems of larger capacity exist. The conclusion to be drawn is that the payload can be handled using current technology.
x	29	"Could" will be changed to "will."
xi	5	The sentence will be rewritten to indicate that once the allowable areal thermal load is selected, waste-package spacing will be determined by the waste-package thermal power, other things being equal. Revised versions will also clarify that, insofar as possible, waste-package thermal power will be a constant for emplacement in a given storage room.
2-1		It is agreed that Table 2-2 is relevant; hence, no change will be made. Providing basic data, such as the assumed depth of the repository and a short description of the site geology in Sec. 2, will be considered.
2-3		The revised impact study will state under parameter DB10 that retrievability is an NRC requirement.
2-5		No change will be made. Elsewhere in the revised impact study, the text will mention that ceramic rails could be used to insert and centralize the waste packages.
2-6		The ANL comment is an observation; no change will be made.
3-1		Section 3 of the revised impact study will be more specific regarding the different waste forms and selection of the PRW-12 package as the only one to be evaluated.
3-6	12-14	In the revised impact study, the initial power levels for the alternative waste packages will be given in Table 3-3.

Page(s)	Line(s)	Action Statement
3-6	22-23	In the revised impact statement, this sentence fragment will be combined with the previous sentence.
3-7		See action statement for page 3-6, lines 12-14. The heat power levels over time for the different cases and burnups will be given as appropriate in Tables 3-1 and 3-3.
3-8	1-20	The revised impact study will state that rod consolidation tests are required to resolve the question of how many PWR assemblies can be combined before temperature limits are violated.
3-8	5	The revised impact study will indicate that the maximum cladding temperature of 375°C is a limit currently imposed by programmatic requirements.
3-8	14-17	In the revised impact study, this sentence fragment will be combined with the previous sentence.
3-9	20-26	It is agreed that item 9 does not consider the possibility of contact between crooked rods. However, because the packing fractions assumed in Westinghouse Electric Corporation (1986) do not allow much room for crooked rods in the waste container, the assumption was made that mild crooks would not affect the heat flux distribution. The revised impact study will clarify this point.
3-13	17	The revised impact study will clarify that an average value for the thermal conductivity was considered adequate because calculated temperatures varied only 10°C or so from those generated using variable thermal conductivity.
3-14		Fluor concurs with the comment; however, no change in the impact study is necessary.
3-15	13-16; 21-23	The revised impact study will clarify that the statements regarding temperature refer to the temperature at the waste package, and not to the temperature in the rooms.
3-16	11-16	The revised impact study will indicate that factors other than waste-package centerline temperature, such as creep rate, retrievability, and uplift, may be more limiting and require a lower areal thermal loading than 24 W/m^2.
3-16	21-23	All storage-hole and slot backfill configurations considered in the revised impact study will be practical from an

Page(s)	Line(s)	Action Statement
		operating standpoint. Thus, while very small air gaps can be considered, only hole configurations with annuli of at least three inches will be considered for the crushed salt backfill cases.
3-16	27-29	The sentence will be modified to indicate that only about one inch of crushed salt can be tolerated.
3-16	29-32	The revised impact study will state that an areal thermal load value of 24 W/m^2 can be obtained by interpolating between the plots in Fig. 3-3. Further, Fig. 3-3 shows that, for a PWR-12 waste package at 24 W/m^2 and a temperature restriction of 175°C, no gap filled with crushed salt can be tolerated.
3-17		Figure 3-2 will be revised to give an ambient (i.e., preemplacement) temperature of 30°C.
3-19	28-30	The words "preferred" and "Section 3.4" will not appear in the revised impact study.
3-20	10-17	See action statement for Sec. 3.7.
3-20	18-21	The paragraph will be expanded to indicate the methods of analysis for peak stress with vertical and horizontal emplacement and the status of verification for these methods.
3-20	22-27	The paragraph will be modified to indicate that field confirmation of the benefit of the air gap is necessary.
3-20	24-27	Future studies will consider the potential for the package to experience shearing when it is located near the surface of an opening.
3-20	28-29	The revised impact study will state that although the analysis in App. C is for a horizontal slot, it represents an upper bound on the behavior of a horizontal borehole.
3-20	30	The ANL comment is out of context. No change will be made.
3-20; 3-21	30-31; 1-2	See action statement for Sec. 3.7.

Page(s)	Line(s)	Action Statement
3-21	6-9	Studies were not conducted to determine the safe minimum burial depth. The revised impact study will indicate that a safe minimum burial depth might be half the room width but that this assumption needs confirmation.
3-21	22-23	The revised impact study will state that although buckling is highly unlikely, the bending stresses caused by nonuniform wall closure must be checked to verify that buckling will not occur in the case of vertical in-pillar emplacement.
3-23	7	The revised impact study will indicate that the studies of horizontal drilling equipment carried out by Robbins Company (1985) were considered. Also, metric and English units will not be mixed.
3-23	11-13	No action is necessary.
3-23	18-20	In future studies, rooms for horizontal emplacement will be 24 ft wide.
3-23	23-26	The decision to use separate vehicles for transport and emplacement will be reconsidered.
3-24		The figure will be replaced by one showing a machine with rails to support the load and hydraulics to adjust the height.
3-26	1-5	The decision to use crawler-type emplacement machines will be reevaluated at the advanced conceptual design stage.
3-26	15-19	Currently used mining equipment will be evaluated to determine if any of its features would be desirable for incorporation into emplacement/transport vehicles.
3-26	19-21	The sentence will be revised to read as suggested by ANL.
3-27	11-15	The revised impact study will state that establishing the feasibility of emplacement does not establish the feasibility of retrieval.
3-28		The figure will be revised to show truncated corners.
3-29	3-7	The revised impact study will clarify the means by which the room dimensions were determined, and the mention of rough wall surfaces will be deleted.

Page(s)	Line(s)	Action Statement
3-33	7-11	The sentence will be altered to refer to "parameters of hoists having high payload capacity."
3-34	10	See action statement for Sec. 3.1, ¶ 1.
3-34	11	See action statement for Sec. 3.1, ¶ 1.
3-34	20-25	See action statement for Sec. 3.1, ¶s 1 and 2.
3-36		The revised impact study will state that packages will be recessed six to seven feet into the pillars.
3-37	1-6	The revised impact study will address the points concerning increasing the number of holes.
3-37	18-19	The sentence will be revised to read as suggested by ANL.
3-37	22-23	See action statement for page 3-37, lines 18-19.
3-37	22-25	The rationale for shortening the waste packages will be explained more clearly in the revised impact study.
3-38	25-28	The revised impact study will indicate that the contribution of the Zircaloy cladding to the engineered barrier system is being evaluated. Further, these sentences will be rewritten to reduce the apparent emphasis on the value of the cladding as a barrier.
3-41	1-4	The paragraph will be rewritten for the revised impact study.
3-41	10-12	The revised impact study will state that separate studies are required to evaluate the potential for free fall, either of conveyance or transfer casks.
3-41	21-23	The revised impact study will not include the following sentence: "However, if we consider the self shielding. . .would probably decrease."
3-42	9-24	The revised impact study will indicate that in the case of breakdown, transfer of the transfer cask to another transporter could not be accomplished in 20-ft-wide rooms. The text will also note that rooms in future studies of horizontal emplacement will be 24 ft wide.

Page(s)	Line(s)	Action Statement
3-42	23-24	The references to "significant advantages" will not appear in the revised impact study.
3-42	28-29	The subsection discussing the transporter will be rewritten and clarified.
3-42	30-31	The reference to decreasing the drift size will be deleted.
3-43	17-18	The reference to "imposing further burdens on safety design" will be removed.
3-44	1	The reference to "multiple package hoisting" will be deleted.
3-44	5-11	It is agreed that if the package length were significantly reduced (e.g., to one-half the length of the reference package), the dimensions of the rooms (width for horizontal emplacement and height for vertical emplacement) could be reduced. No change will be made.
3-44	19-20	The sentence will be revised to read: "While a smaller, lighter transporter would be easier to maneuver, it would need to transport twice as many packages; hence, the wear and tear on the vehicle would increase."
3-45	1-4	The conclusions regarding the relative advantages of Cases 1 and 2 will be reexamined.
3-46		Table 3-7 will be revised to show no advantage for Case 1 over the reference package.
4-1	7-11	These sentences will be rewritten to emphasize the definite beneficial effects of smaller, cooler waste packages.
4-4	19-21	The phrase "as required by DOE (Roy F. Weston, Inc., 1984)" will be added after the reference to younger spent fuel.
4-4	22-27	In the revised impact study, the discussion under the third bullet will clarify that the subject is cladding temperatures. It will also be noted that the analyses depend on having a uniform layer of crushed salt, a condition that may be difficult to achieve.
4-6	1-3	The revised impact study will clarify that various horizontal emplacement options were the only ones considered.

Page(s)	Line(s)	Action Statement
4-6	24-27	The decision to use crawler-type transporter vehicles will be reexamined.
4-7	7-8	See action statement for Sec. 3.1, ¶ 1.
4-7	14-29	The revised impact study will clarify that the dimensions are for horizontal storage only.
4-8	8-10	The revised impact study will state that shorter, lighter packages are desirable from a hoisting and handling standpoint, but that the anticipated waste package weight and dimensions can be handled using conventional hoisting technology.
5-1	2-3	The text of the revised impact study will mention only one recommendation.
5-1	5-10	The revised impact study will state that experimental validation is required.

Impact Study, Appendix A

A-5	15-21	The section will be revised. Typographical errors will be corrected, and dimensional and nondimensional variables will be distinguished from each other.
A-6	22-27	The equations will be revised as suggested.
A-7	10	The equation will be corrected as suggested.
A-8	9, 17, 19	The equations will be corrected as suggested.
A-13		A definition (to include units) will be added for the 33,000 figure.

Impact Study, Appendix B

B-2		The decision to put all of the figures at the end of the appendix will be reconsidered.

Page(s)	Line(s)	Action Statement
B-11	24-28	The paragraph will be revised to read as follows: "For each type of package and each value for the areal loading, calculations were performed with a temperature-dependent expression for the thermal conductivity of salt. This expression, which is based on the quadratic fit in Loken et al. (1984), is presented in Table B-1."
B-13; B-14		The source for the information (i.e., Loken et al., 1984) will be added.
B-13		The revised impact study will state that the thermal conductivity of crushed salt is an assumed value. A footnote will explain why 465 J/kg-K was used instead of the 425 J/kg-K given in the cited reference.
B-14		The assumed burnup of the fuel and the source of the data will be given in the revised impact study.
B-15		Mesh convergence studies will be discussed in the revised impact study. Further discussion is necessary regarding inclusion of the meshes.
B-17	5-31	The description of the "analytical" model will be expanded.
B-19	1-14	The CHESS code will be identified and referenced in the revised impact study.
B-19	15-24	The crossover phenomenon will be explained in the revised impact study.
B-20	25-27	The following explanation will appear in the revised impact study:

"The thermal analyses for this impact study were designed to elucidate the thermal response of five different waste emplacement modes. Because extremely detailed analysis of particular emplacement modes was unwarranted, a two-dimensional approach was decided upon for the initial analysis of Mode 4 (emplacement in crushed salt). More detailed analyses would have been performed if Mode 4 had ultimately been selected as the preferred emplacement mode (which did not happen), or if the temperatures associated with Mode 4 were the critical factor in rejecting this mode (which also did not happen)."

Page(s)	Line(s)	Action Statement
B-21	15-17	The revised impact study will state that although two-dimensional analysis is not conservative, it was considered adequate for an initial evaluation of Mode 4.
B-24	29-32	ANL retracts this comment.
B-27	1-4	The paragraph will be revised as follows: "Calculations have been performed with a temperature-dependent expression for the thermal conductivity of salt. This expression, which is given as a quadratic function of temperature in Loken et al. (1984), is defined in Table B-1."
B-28	9-28	The revised impact study will state that the average room temperature is the temperature at point B in Figs. B-19 and B-22. In addition, the sentence on lines 25-28 will be revised to read: "These results show that the average room temperatures at 50 years are. . . ."
B-28	26-29	Thermal stresses will be discussed in App. C of the revised impact study.
B-31	15-17	The sentence will be revised to read: "The results for the maximum salt temperature for this emplacement mode using the analytic model were reported in Sec. B-3."
B-31	25-29	The word "negligible" will be replaced by "not significant."
B-37		A footnote referring the reader to lines 25-32 on page B-12 where R_r and R_n are defined will be added to each of the figures in which R_r and R_n are used.
B-61 to B-65		It is agreed that the storage hole might not be drilled *exactly* at midpillar height. The revised impact study will state that for simplicity in modeling, the heat sources were placed in the plane of the floor of the entries.
B-67 to B-70		See action statement for pages B-61 to B-65.

Impact Study, Appendix C

Page(s)	Line(s)	Action Statement
C-11	12-18; 23-24	See action statement for Sec. 3.7.
C-12	23-27	No change will be made in the impact study.

Page(s)	Line(s)	Action Statement
C-13	19	The figure cited will be changed to Fig. C-1.
C-14		It is agreed that the density of air has negligible effect on the mechanical response; therefore, the density value need not be changed. The footnotes will indicate that T is in degrees Celsius. Further discussion is required regarding the yield strength assumption for salt.
C-15		The choice of creep law formulation was dictated by ONWI. No change will be made.
C-16		In the revised impact study, the footnote will indicate that T is in degrees Celsius.
C-18	5-29	See action statement for Sec. 3.7.
C-18	14-19	It is agreed that the term "hoop mode" is sometimes used for thick-walled cylinders. No change will be made.
C-18	18-19	See action statement for Sec. 3.7.
C-18	20-23	The assumption that waste packages are centered with ceramic spacers will be stated explicitly.
C-21	3-5	The revised impact statement will indicate that the stated mechanical equivalence assumption is valid because the thickness of the annulus is small compared with the diameter of the waste package. It will further state, however, that the two cases are not thermally equivalent.
C-21	13-14	The revised impact study will state that "two-dimensional analyses are judged adequate to estimate the mechanical response for the purposes of this study. Off-design conditions with highly asymmetric, three-dimensional loads will require more-detailed two- and three-dimensional models."
C-22	23-25	The revised impact study will state that the waste packages will be supported on spacers, if this is found to be necessary.
C-24; C-25	27; 1	The comment is an observation; therefore, no change will be made.
C-25	17	The word "closure" will be substituted for "convergence."

Page(s)	Line(s)	Action Statement
C-26	15-16	It is agreed that use of a higher porosity is conservative, except when retrieval scenarios are being considered. No change will be made.
C-26	19-24	The revised impact study will state that the effect of the consolidation of crushed salt was not considered.
C-26	28-29	The sentence will be replaced with: "However, the horizontal and vertical lines through the room center are planes of symmetry. This symmetry constraint minimizes the shearing response at the planes, thereby reducing the bending loads on a waste canister located near or on a symmetry plane."
C-27	3-19	The revised impact study will reference Sec. 6 of Baumeister et al. (1978) as the source for the plastic yield stress and will state that the value applies for all temperatures expected in the respository. In addition, the revised document will indicate that no allowance was made for corrosion.
C-28	13-21	The first sentence in the section will be revised to read: "The analysis of the flexure of a curved beam, as described in Sec. 5 of Baumeister et al. (1978), was used to estimate the salt stress σ_1 that produces. . . ."
C-28; C-29		Development of the equations for the maximum stress in the steel in the load cases given in Secs. C.3.2.2 and C.3.2.3 will be expanded in the revised impact study.
C-29	18-29	The discussion of "the effects of degradation of the yield stress due to temperature radiation damage, corrosion, etc." will be expanded. The effects of each of these conditions will be discussed explicitly.
C-30	5-6	The revised impact study will state that 792 m is the depth of the proposed repository based on elevations in the Detten No. 1 and J. Friemel No. 1 wells and extrapolated to account for the apparent strike and dip of the LSA4 beds.
C-30; C-31	18-31; 1-6	It is agreed that the beneficial effect of the air gap is overemphasized. Its role will therefore be downplayed in the revised impact study.
C-31	3-4	See action statement for Sec. 3.7.

Page(s)	Line(s)	Action Statement
C-32	2	The validity of the equation will be reexamined. In addition, values for the bulk modulus and thermal expansivity of salt will be provided.
C-32	12-15	See action statement for impact statement, page C-32, line 2.
C-33	7-8	The sentence will be amended to read: "The analytic solution for an infinite line heat source, as given in Carslaw and Jaeger (1959, p. 258), can be used to evaluate the salt temperature for these conditions."
C-33	10	Additional documentation on the integration of the creep equation will be added to the text.
C-37	8-9	The reference will be changed to Fig. C-38.
C-38		The caption will be changed to read: "For Emplacement of a PWR-12 Spent Fuel Package in a Vertical Borehole."
C-39		The computational procedure will be described in more detail in the revised impact study, which will state explicitly that the excavation sequence is not simulated.
C-69		Part (a) will be corrected. Further, the revised impact study will state that mesh convergence studies were not performed.

Impact Study, Appendix D

Page(s)	Line(s)	Action Statement
D-4	3-8	The revised impact study will state that "this appendix was not intended to be a complete description of the process of selecting the proposed preferred emplacement mode and that further information is found in the draft position paper entitled *Evaluation of the Waste Emplacement Mode* (Fluor Technology, Inc., 1985)."
2	2-3	The revised impact study will state that early backfilling is the SRPO position on backfill timing.
2	13-15	The DOE position on retrievability will be referenced in the revised impact study.

Page(s)	Line(s)	Action Statement
3	29-33	The names, technical specialties, and the number of years of experience of the group members will be listed here.
5	24	A footnote will indicate that the want "maximize the excavation rate" was included for completeness only.
12	6	The first adverse consequence for alternative 4 will be repeated for alternative 5. The seriousness of more packages will be given as "low to medium."
12	15-17	A footnote will indicate that the quantity of brine and its effect will be assessed during site characterization and the preemplacement construction phase. It will also state that excessive brines may necessitate abandonment of a prospective site.
12	18	The comment is an observation. No action will be taken.
13	2-4	In the revised impact study, the discussion of the relationship between sleeve deformation and brine accumulation will be expanded and clarified.
13	6	The ratings will be changed to "low" probability and "high" seriousness.
13	7-11	It is not yet clear whether packing around waste containers in sleeved holes will be required. Nevertheless, the discussion of this adverse consequence will be expanded and clarified in the revised impact study.
13	24	The ratings will be changed to "low" and "high" in the revised impact study to be consistent with the values given on page 12 for alternative 7. The remainder of the comment is an observation that does not require any action.

Impact Study, Appendix E

Page(s)	Line(s)	Action Statement
1	25	The requirement for a 12% grade will be reassessed.
1	26-27	The assumption will be revised to read: "assume floor heave may cause local movement."
1	33-34	The assumption will be deleted.

Page(s)	Line(s)	Action Statement
2	14	See action statement for impact study, App. E, page 1, line 25.
2	24; 27	The ranking of the two wants will be reconsidered during the upcoming decision-analysis exercise. Although "mean time to repair" was rated higher because of the potential for workers to be exposed to radiation in the event of transporter breakdown during underground transfer (transfer cask shielding thickness does not allow unlimited worker presence next to the cask), it is also true that consideration of mean time to repair should be balanced against the time elapsed between repairs.
3	4-6	See action statement for impact study, App. E, page 1, line 25.
3; 4	37; 1-3	The significance of want 328 will be reconsidered in the upcoming decision-analysis exercise.
4	12-15	Evidence from salt-mining activities as to the probability of damage to roadways by transporters will be considered during the upcoming decision-analysis exercise.
4	16-18	Evidence from salt-mining operations regarding acceptable bearing pressures will be considered in the upcoming reevaluation of the waste emplacement mode assessment.
5	3-13	A footnote will be added that indicates that other alternatives were considered and dismissed.
5	15-21	A footnote will be added that indicates that although monorails are uncommon in mines, they were considered for the sake of completeness.
5	24-26	ANL retracts this comment as incorrect. The transporter recommended in design studies carried out by Foster-Miller, Inc., for the Nevada Nuclear Waste Storage Investigations is a rubber-tired vehicle with skid steering (Fisk et al., 1985).

Impact Study, Appendix F

F-4	1-17	All decisions made in the course of the impact study were supported by the Kepner-Tregoe analysis and documented

Page(s)	Line(s)	Action Statement
		in the same format, including relatively straightforward decisions for which the documentation format appears to be unnecessarily complex. No change will be made.
1	12-14	The comment is an observation. No change will be made.
2	7-9	The words "to account for uncertainties" will be deleted.
2	21-22	Want 352 will be expanded to indicate that workers in the shaft stations are referred to here.
2	23-24	This comment is an observation and does not require any change in the impact study.
3	17-34	ANL retracts this comment as inappropriate.
F-5	5	See action statement for Sec. 3.1, ¶ 1.
F-5	6	See action statement for page F-5, line 5.
F-5	12	Section F.2 will be revised to indicate that the value of 0.75 is an approximation and that the actual value used in design will result in an acceptable tension ratio and hoist wheel tread pressure.
F-5	14	The revised report will state that a D_{wheel}-to-D_{rope} ratio of 120 was selected for conservatism and exceeds all regulatory requirements and commonly accepted design standards.
F-5	16-19	Section F.2 will be rewritten to state that the use of larger hoist system parameters than the assumed values will yield even larger payload capacities. The discussion will explain that the static suspended load is the subject of the calculation.
F-8	10-18	These calculations will be redone.
F-9; F-10		Section F.2 will be rewritten to indicate that larger hoisting systems exist that would allow larger payloads. In addition, a paragraph to be added at the top of page F-9 will indicate that the calculations on pages F-9 and F-10 were performed to ascertain the effect on the payload of varying the number of hoist ropes.

Page(s)	Line(s)	Action Statement
Impact Study, Appendix G		
G-11	19-25	ANL agrees that the first sentence of its comment is unclear and therefore retracts it. Guidance as to the maximum allowable total weight and size of vehicles will be obtained by evaluating equipment used in salt mines.
G-15		The logic diagram will be added to the introduction of the revised impact study.
Evaluation of Waste Emplacement Mode (draft position paper)		
v	19-24	It is agreed that adverse consequence analysis can serve to verify the final selection. However, if it is used to compare or eliminate alternatives, then the rankings obtained previously, and indeed the entire want analysis, must be considered suspect. The role of adverse consequence analysis will be reconsidered in the upcoming decision-analysis exercise.
vii	1-6	See action statement for draft position paper, page v, lines 19-24.
vii	16	In the upcoming decision-analysis exercise, "uncertainties about waste-package performance and retrievability" will be reflected in the scores rather than in an ex post facto analysis.
vii; viii	28; 1-10	During the reevaluation of the waste emplacement assessment, cost will be an attribute, and projected *direct* excavation and emplacement costs will be considered for each alternative.
viii	11-18	The discussion will be revised to better explain the role of emplacement difficulties and waste-package performance in the decision process.
viii	19-33	The discussion of entry backfilling and waste-package performance will be expanded so that their roles in the decision process are more clearly defined.

Page(s)	Line(s)	Action Statement
1-1	17	The text will be modified such that the document entitled *Generic Requirements for a Mined Geologic Disposal System* (Roy F. Weston, Inc., 1984) is referenced instead of "DOE Generic Requirements."
1-1	27-29	The sentences "Salt Vault Engineers. . .emplacement orientation," and The potential for vertical. . .was not considered" are inappropriate and will be deleted.
1-1; 1-2	31; 1-2	The statement will be deleted.
1-2	6-7	The phrase "with very little basis" will be deleted.
1-2	18-19	The word "preferred" will be substituted for "most desirable."
1-3	12-14	The sentence will be revised to read: "A group of 16 panelists knowledgeable in various aspects. . . ."
1-3	16-18	This paragraph will be revised to clarify that adverse consequences are being discussed; the reference to advantages and disadvantages will be deleted.
1-3	21-25	The sentence will be revised to read: "Because of licensing and quality assurance requirements and the sensitivity of repository design, the decisions made during waste repository design will be fully documented."
1-3	25-28	In the reevaluation of the waste emplacement mode, cost will be an attribute in the analysis and will not be used as the sole basis for disqualification of alternatives.
1-4	3-24	These four paragraphs are inappropriate and will be deleted.
1-5	11-27	Every effort was apparently made to ensure that dominant personalities did not dominate. Fluor is now cognizant of the potential drawbacks of the methodology used and will be conducting a new decision analysis of the Harvard-MIT type that should be sufficiently rigorous. If it is, this approach should result in a correct decision. No further action will be taken.
1-5; 1-6	28-31; 1-8	In the revised position paper, care will be taken to eliminate any bias against storage in vertical holes.

Page(s)	Line(s)	Action Statement
1-6	31-34	The last two sentences of the paragraph will be modified to read: "Bias, incompleteness, and even inefficiency can be greatly reduced by using a formal decision-analysis approach. The Kepner-Tregoe methodology, while not as rigorous as the Harvard-MIT approach, can be used to achieve the same objectives in situations where time is of the essence and rigorous justification of the decision (e.g., in a public hearing) is not required. Fluor selected the Kepner-Tregoe process for the initial evaluation of the waste emplacement mode for the repository in salt for this reason. Subsequent analysis will use more formal methods of the Harvard-MIT type."
2-1	5	The word "retrieval" will be inserted after "operation."
2-1	15-16	The revised position paper will state that "the horizontal, sleeved borehole ranked highest based on the want attributes. However, in a postoptimality analysis, the cost of sleeves was considered excessive; hence, in the so-called balanced choice, the sleeved option ranked second."
2-1	15-30	The draft DOE position paper on retrievability (U.S. Department of Energy, 1985) will be cited here as the source of the retrievability requirements.
2-2	1-3	The criteria for a preferred horizon will be given in a footnote.
2-2	12-14	The revised position paper will clarify that, although the cross-sectional area of rooms for horizontal and vertical emplacement would not differ greatly, total repository excavation for horizontal emplacement would be approximately half that required for vertical emplacement, other things being equal. This disparity occurs because, for a given length of storage room, two packages can be emplaced horizontally for every one emplaced vertically.
2-2	15-17	It is agreed that within the height limits under consideration, there would be little significant difference in stability between horizontal and vertical openings, other things being equal. Therefore, these two sentences will be deleted.
2-2	18-21	The potential for damaging a waste package during retrieval will be reconsidered.

Page(s)	Line(s)	Action Statement
2-2	22-25	The second sentence will be replaced by: "Equipment development and demonstration are in progress at the Waste Isolation Pilot Plant; the experience gained should provide a measure of confidence in the practicability of horizontal emplacement."
2-2	26-28	The revised position paper will point out that statements regarding magnitudes of stresses and displacements must be considered tentative until models incorporating detailed lithology have been run using a realistic constitutive model for salt creep.
2-3	1-2	The sentence will be revised to read: "The temperatures in the host rock that result from waste-package emplacement will not be significantly different for the horizontal and vertical borehole concepts."
3-1	3-5	The following reports will be referenced in the revised position paper: • *Nuclear Waste Repository in Basalt: Preconceptual Design Report*, Rockwell Hanford Operations, RHO-BWI-CD-35 (Feb. 1980). • *Basalt Waste Isolation Project, Task V: Engineering Study No. 7, Waste Emplacement Optimization*, prepared by Raymond Kaiser Engineers and Parsons Brinckerhoff, Quade & Douglas, Inc., for Rockwell Hanford Operations, SK-BWI-ES-018 (June 1984). • *Nevada Nuclear Waste Storage Investigations, Preliminary Repository Concepts Report*, Sandia National Laboratories, SAND 83-1877 (1983). • *Immobilized Waste Vault: Design Concepts and Layouts*, prepared by Acres Consulting Services, Ltd., for Atomic Energy of Canada, Ltd., Chalk River, Ontario, Canada, TR-60 (Dec. 1980). • *Irradiated Fuel Vault: Design Concepts and Layouts*, prepared by Acres Consulting Services, Ltd., for Atomic Energy of Canada, Ltd., TR-59 (Nov. 1980).
3-2	1	Project criteria will be included in the revised position paper.

Page(s)	Line(s)	Action Statement
3-3 to 3-9		It will be clarified in both the revised impact study and the revised position paper that 60 concepts were initially identified, of which only 17 were considered worthy of further study and consideration in the decision analysis.
3-9	5	The words "was eliminated" will be changed to "was not eliminated."
4-1	2-4	The text of the revised position paper will be more specific regarding what is being evaluated.
4-1	6	The revised position paper will give such details as the dimensions and weight of the waste package.
4-1	21-22	The first sentence of item 5 will read as suggested by ANL. A technical description of LSA 4 salt will be added.
4-2	2-3	The reference citation will include the statement that a copy of this draft report can be viewed in the Battelle Project Management Division library in Columbus, Ohio.
4-2	9-12	The pertinent reference, "Westinghouse Electric Corporation, 1986," will be provided in the revised position paper.
4-4	4	No change will be made in the position paper.
4-5	2-12	It is agreed that some of the wants are probably not independent. In the upcoming reevaluation of the waste emplacement mode decision, particular attention will be paid to selection of objectives and attributes that are independent to the extent practicable.
4-6	2-18	It is agreed that wants may be related for some of the emplacement modes. Particular attention will be paid to this problem in the reevaluation of the waste emplacement mode decision. See action statement for draft position paper, page 4-5, lines 2-12.
4-7	1	See action statement for Sec. 2.1.
4-7	12	The revised position paper will clarify what is meant by geologic stability.

Page(s)	Line(s)	Action Statement
4-7	17	This want (maximize far-field geologic integrity during retrieval) will be deleted.
4-7	20	See action statement for draft position paper, page 4-7, line 1.
5-1	20	The word "operational" will be inserted as suggested by ANL.
5-2	20-27	The comment is an observation amplifying some of the concerns in the discussion at this point. It is agreed that the concept meets the must criteria. Therefore, no change in the draft position paper will be made.
5-3	15-17	The weights assigned to the three sections will be rounded to two significant digits.
5-3	24-26	The reevaluation of the waste emplacement mode decision will use multiattribute utility theory as part of the formal decision analysis. Objective, or "natural," scales will be used whenever possible. Subjective, or "constructed," scales will be used when the concern does not lend itself to quantification.
5-4	12-14	Retrieval from an unsleeved, vertical hole will be reconsidered in the reevaluation of the emplacement mode decision.
5-4	24-27	It is agreed that summarizing the sequence of operations here would be inappropriate. However, a sentence will be added that indicates that backfilling is assumed to occur within two years of storage based on the SRPO position on backfilling (Fluor Technology, Inc., 1986); hence, retrieval is assumed to be from a backfilled room. The revised position paper will also state that in the cases of alternatives 4 and 5, the waste packages will interfere with remining operations.
5-4	27-30	The discussion of the retrieval problems inherent in alternatives 4 and 5 will be expanded.
5-5		The assumption that vertical holes would be the only ones requiring two-pass mining will be reexamined. In addition, scores for the excavation and retrieval wants will be reconsidered in the reevaluation of the waste emplacement mode decision.

Page(s)	Line(s)	Action Statement
5-6	6-9	The "undesirability" of excavating the only slightly higher openings required for vertical storage will be reconsidered.
5-7	3-6	The revised discussion of retrieval from sleeved holes will clarify the type of operation assumed.
5-9	14-19	Cost will be an attribute in the reevaluation of the waste emplacement mode decision.
6-1	15-23	The assumption that the level of safety varies inversely with the tonnage removed and the height of openings will be reexamined.
6-1	21	The words "greater entries" will be replaced by "higher entries."
6-2		The figure will be changed to a bar graph, and the appropriate page numbers will be added to show where each want is discussed.
6-3	13-19	The revised position paper will state that room stability depends more on roof condition than on the height of the walls and that wall stability depends on the width-to-height ratio of the pillars.
6-4	3-9	Assumptions made regarding the ease of excavation of the different alternatives will be reexamined in the reevaluation of the waste emplacement mode decision.
6-4	20-23	See action statement for recommendation 2. Also, additional information will be sought about the potential effect of nonsalt interbeds on waste-package performance, and a discussion of these effects (if any) will be included in the revised impact statement. Discussion will also be added on the expected range of movement of a horizontal emplacement machine that could be used to slightly adjust the package elevation to account for local variations in nonsalt seam location.
6-5	1-10	Assumptions regarding the extreme difficulty of retrieval from vertical holes will be reexamined.
6-5	2-4	The position paper will be revised to be consistent with page 23 of App. C.
6-5	11-15	The scores for this want will be reexamined.

Page(s)	Line(s)	Action Statement
6-5	16-19	The scores for this want will be reconsidered.
7-1		In the revised position paper, the reference citation will include a statement that the report can be seen at the Battelle Project Management Division library in Columbus, Ohio.

Position Paper, Appendix A

A-4	12-27	The assumption that separate equipment will be used for transport and emplacement will be reconsidered.
A-5	20-21	The assumption that the pintle can be adequately engaged will be reconsidered.
A-6	12-20	See action statement for draft position paper, page A-4, lines 12-27.
A-7	21-22	See action statement for draft position paper, page A-5, lines 20-21.
A-8		ANL retracts this comment. Upon further investigation, ANL learned that excavation of such a slot can be performed by an undercutter.
A-9	6	See action statement for page A-8, immediately above.
A-9	12	The comment was an observation, and no change will be made.
A-9	24	Retrieval procedures will be reexamined.
A-10		See action statement for draft position paper, page A-8.
A-11	4	The dimensions will be changed in Fig. A-3 to conform with those in the text.
A-11	6	See action statement for draft position paper, page A-8.
A-11	23	The operation to expose the waste package will be clarified in the revised position paper.
A-11	24	See action statement for draft position paper, page A-9, line 24.

Page(s)	Line(s)	Action Statement
A-12		ANL retracts this comment as inappropriate.
A-13	6	ANL retracts this statement.
A-13	17-23	The revised position paper will clarify that these operations will be carried out by remote control.
A-14		See action statement for draft position paper, page A-8.
A-15	21-25	See action statement for draft position paper, page A-13, lines 17-23.
A-15	24	See action statement for draft position paper, page A-11, line 23.
A-17		Excavation of these slots will be reexamined.
A-18	19-23	See action statement for draft position paper, page A-13, lines 7-33.
A-20	9	ANL retracts this comment. Recent discussions with NRC indicate that immediate backfilling might be accepted under certain conditions.
A-20	19-20	It is agreed that cutting the slots may not be easy and that further study may be required. This operation will be reevaluated in the revised decision-analysis procedure.
A-22	9	See action statement for draft position paper, page A-20, line 9.
A-26	11-12	See action statement for draft position paper, page A-20, line 9.
A-26	16-22	The revised position paper will clarify that, in completely backfilled rooms, the intent was to establish the new floor nine feet below the old roof line and that, in partially backfilled rooms, the intent was to intercept the waste packages.
A-28		ANL retracts this comment.
A-29	12-13	See action statement for draft position paper, page A-20, line 9.
A-29	19-21	The revised position paper will clarify that interception of the waste packages was intended.

Page(s)	Line(s)	Action Statement
A-32	11-12	See action statement for draft position paper, page A-20, line 9.
A-32	17-19	See action statement for draft position paper, page A-26, lines 16-22.
A-35	16-22	The revised position paper will clarify that the description was not intended to detail actual emplacement procedures or represent storage-hole design. The revised document will also state that it was assumed that packing in the annulus will not be required and that an air gap will provide a better thermal environment than a gap filled with crushed salt.
A-36	1-13	The revised position paper will clarify that a backup gripping mechanism may be required if the pintle has corroded. It is agreed that overcoring over the sleeve would result in the need to handle large-diameter, heavy units.
A-36	6-7	The revised position paper will clarify that backfill removal will take place between the storage-room wall and the near end of the waste package.
A-37	15-21	See action statement for draft position paper, page A-35, lines 16-22.
A-37	28	The word "sleeve" will be replaced by shield "plug."
A-38	1-13	The revised position paper will clarify that a backup gripping mechanism may be required if the pintle is corroded. The reference to sleeve alignment in statement 5.1 will be deleted; no sleeve is used in this concept. The revised version will also state that excavation/overcoring would be required in this case.
A-40	10-12	It is agreed that the drilling system falls within the category of reasonably available technology. No change will be made, as the comment is simply an observation.
A-41	15-16	The revised position paper will clarify that there is no backfill beyond the waste packages closest to the openings.
A-41	19-22	The revised position paper will state that backup grabbing mechanisms will be available in case of excessive pintle corrosion. It will also note that retrieval of interior waste

Page(s)	Line(s)	Action Statement
		packages may be hazardous and difficult in the case of breached or wedged-in-place packages.
A-42	25-26	See action statement for draft position paper, page A-35, lines 16-22.
A-43	11-13	It is agreed that retrieval would be a costly, time-consuming process. No change will be made to the position paper.

Position Paper, Appendix C

Page(s)	Line(s)	Action Statement
3	24-30	It is agreed that areal thermal load does not affect the very-near-field temperature; therefore, ANL retracts its comment as inappropriate in this context.
10	9	See action statement for Sec. 2.1.
13		See action statement for draft position paper, page 5-5.
14	20-22	The assumption that a package could be damaged during insertion into the borehole will be reconsidered during the reevaluation of the waste emplacement mode decision.
16	29-32	Cost will be an attribute in the reevaluation of the waste emplacement mode decision.
16	39-42	In the reevaluation of the waste emplacement mode decision, the problems related to emplacing the waste packages and packing in the long boreholes will be more clearly reflected in the scores for individual attributes for this emplacement mode.
17	5-24	In the reevaluation of the waste emplacement mode decision, care will be taken to ensure that the attribute list is sufficiently inclusive that drawbacks (to particular concepts) that might rule them out are already accounted for.
19		The revised position paper will clarify that cutting the slots is considered under emplacement rather than excavation. The capabilities of continuous mining equipment will be reevaluated so that the detailed mining sequence (i.e., number of passes) for each alternative is projected.

Page(s)	Line(s)	Action Statement
		The scores for "maximize safety" and "maximize stability" will be reconsidered in the reevaluation of the waste emplacement mode decision.
20	1-19	The scores for "maximize safety" will be reevaluated using a more comprehensive criterion than the inverse of the volume excavated.
21	1-12	The scores for "maximize stability" will be reevaluated.
21	30-31	The revised position paper will clarify that excavation of the slots was considered part of emplacement; that is, it was not considered under this want attribute. It will also clarify why alternative 2 scores low while the other slot alternatives do not.
23		The revised position paper will explain why the long holes score lower than the short holes under the want "maximize radiation protection for workers."
		The rating for alternative 3C will be equal to that for alternatives 3 and 3B for the want "maximize flexibility to vary package spacing." In addition, the discussion on page 26 will be expanded so that the rationale for the low score for alternative 2 is clearer.
28		The scores for the want "maximize ability to control contamination" will be reconsidered in the reevaluation of the waste emplacement mode decision.
		The scores for the want "maximize near-field geologic stability" will be reconsidered in the reevaluation of the waste emplacement mode decision.
		It was agreed that the want objective "maximize far-field geologic integrity during retrieval" is irrelevant. Since it will not be included in the reevaluation of the waste emplacement mode decision, no action will be taken regarding the scores for that want.
29	8-11	The scores for the want "maximize preservation of waste package integrity" will be reconsidered during the reevaluation of the waste emplacement mode decision.
29	31-35	See action statement for draft position paper, App. C, page 28 (first comment).

Page(s)	Line(s)	Action Statement
30	7-12	See action statement for draft position paper, App. C, page 28 (second comment).
30	26-28	The score for long, sleeved, horizontal holes under the want "maximize simplicity of retrieval operations" will be reconsidered in the reevaluation of the waste emplacement mode decision.
30	33-36	The scores for the want "maximize simplicity of retrieval operations" will be reconsidered in the reevaluation of the waste emplacement mode decision.
31	9-17	The want "maximize the far-field geologic integrity" will not be considered in the reevaluation of the waste emplacement mode decision.

Position Paper, Appendix D

D-1		A list of acronyms and appropriate references will be provided in the revised position paper.

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CONCURRENCE SHEET

I concur with the responses, as presented in App. C, to the recommendations and comments of Argonne's review report entitled *Radioactive Waste Isolation in Salt: Peer Review of the Fluor Technology, Inc., Report and Position Paper Concerning Waste Emplacement Mode and Its Effect on Repository Conceptual Design.*

D.K. Robinette 1/16/87

D.K. Robinette, Salt Repository Project Office

W. Harrison

W. Harrison, Argonne National Laboratory

J.K. Clark 1-12-87

J.K. Clark, Fluor Technology, Inc.

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CONCURRENCE SHEET

[illegible] the comments [illegible] and comments [illegible] review [illegible] Fluor Technology [illegible]

[illegible], Salt Repository Project [illegible]

W. [illegible]

[illegible], Fluor Technology, Inc.

APPENDIX D

CREDENTIALS OF PEER REVIEW PANEL MEMBERS

Thomas R. Bump

University of Oklahoma: NROTC V-12 Engineering Curriculum (1945)
Iowa State University: B.S., Mechanical Engineering (1948)
Iowa State University: M.S., Mechanical Engineering (1949)
Purdue University: Ph.D., Mechanical Engineering (1955)
Registered Professional Mechanical Engineer, No. 62-20370, State of Illinois

Dr. Bump is a Senior Mechanical Engineer in Argonne National Laboratory's Materials and Components Technology Division, where he provides technical support to the Crystalline Repository Project Office of DOE's Chicago Operations Office and designs components for advanced liquid metal reactors.

From 1973 to 1984, he was manager of the Mechanical and Heat Transfer Components Section, whose members studied flow and mixing processes, evaluated the thermal performance and stability of steam generators, and designed samplers for pressurized coal gasifiers. Almost all of this work was in direct support of DOE liquid metal reactor vendors.

Over this same period, Dr. Bump (1) served as a project manager for a NRC program researching the penetration integrity of reactor containment systems; (2) provided technical support to DOE's Transportation Operations and Traffic Management Office; (3) was team leader and member of a group charged with evaluating pressurized-water-reactor topical reports for NRC; (4) was contract engineer for procurement of very large liquid metal reactor pumps and steam generators; (5) designed thermal-hydraulic-mechanical components and systems related to nuclear and fossil power facilities; and (6) developed programs on the use of radioisotopes for heating in arctic regions, ocean thermal energy conversion, and plastic heat exchangers.

From 1955 to 1973, also at Argonne and as a project engineer and group leader, Dr. Bump developed and applied methods for predicting the accommodation of liquid metal reactor cores to fast-neutron-induced creep and swelling of steel. Related work concerned the failure of reactor fuel elements, heat transfer in liquid metals, the steady and transient behavior of power plants, the flow characteristics of bundles of fuel elements, the performance of novel heat exchangers, the thermal response of complex structures, and the interactions between bowing fuel assemblies. Much of this effort was directed toward the Experimental Breeder Reactor-II and the Fast Flux Test Reactor, both of which are still operating -- the former for more than 20 years. Dr. Bump has received three awards for being a key member of the EBR-II design team.

Dr. Bump has authored approximately 55 papers and reports, and is a member of the Advanced Reactors Committee of the American Association of Mechanical Engineers and the Nuclear Committee of the American Power Conference.

Joseph S. Busch

Northwestern University: B.S., Chemical Engineering (1949)
Johns Hopkins University: M.S., Chemical Engineering (1953)
Carnegie Mellon University: Ph.D., Chemical Engineering (1960)

Dr. Busch is Principal Engineer with Raymond Kaiser Engineers, Oakland, Calif. He has 32 years experience working on nuclear and chemical engineering projects for both government and industry. He has supervisory and design experience with solid-, liquid-, and gas-processing systems for nuclear and nonnuclear facilities. His nuclear experience includes work on both fast reactors and light-water reactors.

Dr. Busch participated in the National Waste Terminal Storage Program by working on a conceptual design for a mined repository in salt for highly radioactive waste. He was assistant project manager in charge of underground technology and also served as head of the thermal analysis group. As such he directed the work of mining, rock mechanics, heat transfer, and ventilation engineers and consultants, and coordinated the design of subsurface systems with that of surface facilities. Dr. Busch also served as manager of a preconceptual design of an incinerator facility to be constructed at Idaho National Engineering Laboratory. He has also participated in the Basalt Waste Isolation Project and the Nevada Nuclear Waste Storage Investigation.

A registered chemical engineer in Pennsylvania, Michigan, Mississippi, and New York, Dr. Busch has published numerous papers on heat transfer, nuclear systems, and pollution abatement.

Larry E. Fischer

Stanford University: B.S., Mechanical Engineering (1963)
University of California, Los Angeles: M.S., Mechanical Engineering (1966)

Mr. Fischer has been a project leader for Lawrence Livermore National Laboratory since 1983. Having extensive experience in nuclear systems and equipment, he is currently responsible for developing criteria for NRC to control the fabrication and operation of shipping containers and for evaluating the adequacy of current commission transportation regulations. Mr. Fischer also provides support for DOE by reviewing waste canisters designed for nuclear waste disposal in tuff and for NRC by evaluating Topical Safety Analysis Reports submitted for the on-site storage of nuclear spent fuel.

Before joining Lawrence Livermore, Mr. Fischer worked for Nutech (1982-1983), General Electric, Nuclear Operations (1970-1982), United Technologies Corporation (1965-1970), and Hughes Aircraft (1963-1965). While at General Electric, Mr. Fischer was responsible for overseeing the design of the boiling water reactor and led the preparation and issuance of key boiling-water-reactor documents that specify decay heat removal, nuclear safety classification, and equipment classification.

Mr. Fischer is author and coauthor of seven reports, papers, and computer codes on nuclear power generation and on materials transport and storage. He is a member of four professional organizations and holds two patents on nuclear reactor control systems.

Douglas F. Hambley

Queen's University at Kingston, Canada: B.Sc., Mining Engineering (1972)
Lewis University: M.B.A., Finance and Operations Management (1986)
Registered Professional Engineer, No. 18026014, Province of Ontario
Registered Professional Engineer, No. 062-039201, State of Illinois

Mr. Hambley has extensive experience in mining, tunneling, and underground construction. He has been a member of the Engineering Geosciences Group of the Energy and Environmental Systems Division at Argonne National Laboratory since 1984. In addition to his duties as the core peer review panelist responsible for mining engineering and rock mechanics, he has been a consultant to Fermi National Accelerator Laboratory on tunneling and siting considerations for the proposed Superconducting Supercollider Accelerator and has participated in an Argonne Environmental Research Division study on Greater Confinement Disposal for low-level nuclear waste.

From 1980 to 1984 he was Senior Mining Engineer with Engineers International, Inc., a mining/tunneling consulting firm. He was Project Engineer on several major projects, including NRC contracts to assess retrievability from high-level radioactive waste repositories and to provide technical assistance for repository design reviews.

Between 1972 and 1980, Mr. Hambley held operating and staff-engineering positions with major Canadian mining companies and consulting firms. During his employment at Denison Mines Ltd. (1977-1980), he was responsible for several major projects in addition to his duties as the mine's Rock Mechanics Engineer.

Mr. Hambley is author and coauthor of journal articles, conference presentations, and government agency contract reports on retrievability of high-level radioactive wastes, computer modeling of mine openings, repository ventilation, design of shafts and tunnels, and raise-boring cost estimation, in addition to the technical memoranda generated as a result of peer review activities. He is a member of the national Rock Mechanics Committee of the Association of Engineering Geologists and is chairman of the Chicago Section of the Society of Mining Engineers.

Wyman Harrison

University of Chicago: S.B., Geology (1953), after three years of undergraduate work at Stanford University
University of Chicago: S.M., Geology (1954)
University of Chicago: Ph.D., Geology (1956)
Registered Geologist, No. 2476, State of California
Certified Professional Geologist, No. 134, American Institute of Professional Geologists, and No. 487, State of Virginia

Dr. Harrison is Associate Director for Engineering Geosciences for Argonne National Laboratory's Energy and Environmental Systems Division. He directs a 25-person group that performs analytical and experimental studies related to management of energy and mineral resources and to development and deployment of related technologies. Major activities of the group include (1) acquisition of geophysical and geotechnical data bases, (2) analysis of the data of geoscience to support design and deployment of energy technologies, and (3) development of physical and mathematical models of geophysical and geotechnical systems.

Dr. Harrison's group recently completed comprehensive surveys of geoscience data pertaining to crystalline rock complexes in the northeastern and Lake Superior regions of the United States to help assess their potential as possible sites for repositories for high-level radioactive waste. He and his group were the first to demonstrate the value of formal decision analysis for determining the relative favorability of specific crystalline rock areas for such repositories. Dr. Harrison has conducted numerous other geotechnical projects at Argonne, ranging from field studies of the feasibility of using dredged material to reclaim abandoned mined lands to projecting future Soviet oil output by assessing the development of its giant fields.

From 1971 to 1975, Dr. Harrison was Professor of Geography (Associate Department Chairman) at the University of Toronto, where he specialized in studies of slope stability in sedimentary terrains and the siting of supertanker ports. Before that, he was Associate Director for Physical, Chemical, and Geological Oceanography at the Virginia Institute of Marine Science and Professor of Marine Science at the College of William and Mary. Dr. Harrison was Director of the Environmental Science Services Administration's (now National Oceanic and Atmospheric Administration's) Land and Sea Interaction Laboratory from 1964 to 1968. Earlier he was on the faculty of Dartmouth College's Department of Geology and a geologist with the Indiana Geological Survey.

An author of more than 125 papers, reports, reviews, and books, Dr. Harrison was made Senior Scientist at Argonne in 1976.

Charles H. Jacoby

Missouri School of Mines and Metallurgy: B.S., Mining Engineering (1941)

Mr. Jacoby has extensive experience in conducting exploration and feasibility studies related to salt domes. He is presently Consulting Engineer for Jacoby and Company Inc., and consults on various problems related to salt exploration, evaluation, recovery, and storage capacity. From 1953 to 1977, he was Director of Development for International Salt Company, where he gained extensive experience in the directed development of salt mines all over the world. His work included evaluating and studying the emplacement of hazardous and toxic materials in salt deposits. Before 1953, Mr. Jacoby worked in manganese exploration and evaluation for several corporations and U.S. government offices.

Some of Mr. Jacoby's recent consulting activities have included (1) economic evaluation of salt reserves, (2) creation of propane storage cavities in bedded salt, (3) design of deep well disposal systems in salt to combat and prevent pollution, and (4) establishment of design criteria for creating cavities in salt for ONWI.

Mr. Jacoby holds 22 U.S. patents dealing with salt mining, brine field revival, hydraulic fracturing, and geothermal systems. He has published more than 30 papers in his areas of expertise and is a member of 12 professional societies.

Lyle D. McGinnis

St. Norbert College: B.S., Physics (1954)
St. Louis University: M.Sc., Geophysics (1960)
University of Illinois, Champaign-Urbana: Ph.D., Geology (1965)

Dr. McGinnis is Manager of the Geology and Geophysics Section of Argonne National Laboratory's Energy and Environmental Systems Division. Before assuming his position with Argonne, he served as Professor and Chairman of the Geology Department at Louisiana State University (1983-1985). He also served as Chairman of the Geology Department at Northern Illinois University (1980-1983), where he taught geophysics and geology since 1967. Dr. McGinnis's specialties include solid earth geophysics, exploration geophysics, tectonics, and polar geophysics. He has received more than 30 research grants and awards throughout his career.

As a professor at Northern Illinois University, Dr. McGinnis's research focused primarily on gravity fields and on tectonics in continental interiors. His work included gravity studies in the continental interior of North America; gravity, magnetic, and seismic studies in Antarctica; management of the Dry Valley Drilling Project, Antarctica; and seismic studies of the Atlantic continental shelf.

Before joining the staff at Northern Illinois University, Dr. McGinnis was a Technical Expert with the United Nations Development Program in Afghanistan (1966-1967). There he conducted electrical resistivity studies and completed the first regional gravity study of Afghanistan. In addition, Dr. McGinnis has worked as a geophysicist for the Illinois Geological Survey (1960-1966), for the International Geophysical Year in Antarctica (1957-1959), and for the Carter Oil Company (1954-1955).

Dr. McGinnis has been an author and coauthor of more than 100 publications. He has been a coauthor and editor of four books and has published four gravity maps. He is an active member of eight professional organizations and honorary societies, and is the U.S. representative to the Scientific Committee for Antarctic Research (SCAR) on solid earth geophysics.

Dennis Z. Mraz

University of Ostrava, Czechoslovakia: M.Sc., Mining Engineering and Construction (1962)
University of Ostrava, Czechoslovakia: completed one year of a Ph.D. program
Mine Managers Certification, No. 523, Province of Alberta

Mr. Mraz is most recently President of Mraz Project Consultants, Ltd., Saskatoon, Saskatchewan. From 1981 to 1984, he was with Denison Mines, Ltd., as Vice President of Operations for Dentherm Resources, Ltd.; with Quintette Coal, Ltd., as Vice President and General Manager-Operations; and with Potacan Potash Company as an internal consultant. As General Manager for Luscar-Sterco, Ltd. (1978-1981), Mr. Mraz was responsible for operating a surface-mining operation and designing the underground mining operation. From 1969 to 1978, he was Engineering Manager for International Minerals and Chemical Corp. (Canada) Ltd., where he was, among other things, directly responsible for engineering research and development for underground mining operations.

His consulting activities have included studying rock mechanics, designing mining methods, preparing guidelines for safety pillars in shafts and exploration holes, and spacing solution caverns in deep salt formations. Since 1982, Mr. Mraz has been advisor to the Department of Earth Sciences, University of Waterloo, on studies associated with testing salt rocks.

Mr. Mraz is a member of five professional organizations and has written seven papers dealing with plasticity and flow of salt and how they affect design of mining methods.

James E. Russell

South Dakota School of Mines and Technology: B.S., Civil Engineering (1963)
South Dakota School of Mines and Technology: M.S., Civil Engineering (1964)
Northwestern University: Ph.D., Theoretical and Applied Mechanics (1966)

Dr. Russell joined the faculty of Texas A&M University in 1978 as Professor of Mining Engineering and Geophysics, and has been a Brockett Professor of Engineering since 1982. He has had extensive experience in the analytical-numerical, laboratory, and field aspects of rock mechanics. Much of his research has related to mining, underground construction, and underground storage, with special emphasis on in situ experiments related to waste repository design, radioactive waste isolation in salt, creep models for salt, thermal loading in waste repositories in salt, benchmark problems in salt using different numerical methods, coal gasification, and lignite mining.

Dr. Russell serves as a rock mechanics consultant to ONWI and Oak Ridge National Laboratory; as a resource consultant for rock mechanics to the Overview Committee for the Basalt Waste Isolation Project; as a coinvestigator of an ONWI-sponsored project at Texas A&M University to develop constitutive equations for salt; and as a member of the Performance Constraints Working Group for RE/SPEC, Inc., and ONWI. During 1979 he served as a member of the Peer Review Group for DOE's Nevada Nuclear Waste Storage Investigations.

From 1977 to 1978, just prior to accepting the position at Texas A&M, Dr. Russell was the Project Manager for Rock Mechanics at the Office of Waste Isolation, Union Carbide Corporation. From 1972 to 1976, he was Vice President and Resident Consultant at RE/SPEC, Inc. From 1967 to 1976, Dr. Russell served as Assistant Professor of Civil Engineering; Associate Professor of Civil Engineering, Mining and Civil Engineering, and Mining Engineering; and Professor of Mining Engineering at the South Dakota School of Mines and Technology. From 1966 to 1967, he was Senior Research Engineer at Southwest Research Institute.

Dr. Russell has published extensively in the fields of rock mechanics, mining engineering, lignite mining, coal gasification, and waste isolation. He is a member of six professional and honorary societies, and has served on 11 national committees.

Ronald G. Whitfield

University of Pittsburgh: B.S.E.E., Electrical Engineering (1966)
Massachusetts Institute of Technology: S.M.E.E., Electrical Engineering (1968)
Illinois Institute of Technology: Ph.D., Industrial and Systems Engineering (1975)

Dr. Whitfield is Manager of Decision Analysis Programs for the Decision Analysis and Systems Evaluation Section at Argonne National Laboratory. Since joining Argonne in 1978 as an Assistant Environmental Scientist, Dr. Whitfield has assessed the health risks of alternative national ambient air quality standards for lead using the probabilistic judgments of health experts (EPA) and has assisted in developing a method for identifying the most favorable locations in crystalline rocks for disposal of high-level radioactive waste (DOE). Dr. Whitfield has also used decision-analysis methods to evaluate Argonne research programs.

From 1966 to 1977, Dr. Whitfield was Member of Technical Staff at Bell Telephone Laboratories, where he applied systems engineering techniques to numerous telephone problems, including planning future switching systems in both local and toll environments. Dr. Whitfield also taught courses in applied probability and in operations research for his employer's Continuing Education Program. From 1977 to 1978, he worked as Staff Statistician for Illinois Bell Telephone Company, where he developed an econometric model to describe the demand for intrastate toll messages.

Dr. Whitfield is a member of seven professional organizations and honorary societies, and is author and coauthor of 23 technical reports and journal articles. He has given six talks related to decision analysis and has given three lectures for the Egyptian Power Plant Authority in Cairo, Egypt, as part of a course on project management techniques sponsored by the International Atomic Energy Agency.